NASA/TM—2006-214353

Weather Information Communication (WINCOMM) VDL–3 and 1090ES Final Test Requirements, Test Plans, and Test Results

James H. Griner
Glenn Research Center, Cleveland, Ohio

Russ Jirberg
Lake Logic Systems, Cleveland, Ohio

Brian Frantz
Verizon Federal Network Systems, Cleveland, Ohio

Brian A. Kachmar
Analex Corporation, Brook Park, Ohio

June 2006

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National Aeronautics and
Space Administration

Glenn Research Center
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National Aeronautics and Space Administration
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Russ Jirberg
Lake Logic Systems
Cleveland, Ohio 44134

Brian Frante
Verizon Federal Network Systems
Cleveland, Ohio 44135

Brian A. Kachmar
Analex Corporation
Brook Park, Ohio 44142

Abstract

NASA's Aviation Safety Program was created for the purpose of making a significant reduction in the incidents of weather related aviation accidents by improving situational awareness. The objectives of that program are being met in part through advances in weather sensor technology, and in part through advances in the communications technology that are developed for use in the National Airspace System. It is this latter element, i.e., the improvements in aviation communication technologies, that is the focus of the Weather Information Communications project. This report describes the final flight test results completed under the WINCOMM project at the NASA Glenn Research Center of the 1090 Extended Squitter (1090ES) and VDL Mode 3 (VDL–3) data links as a medium for weather data exchange. It presents the use of 1090ES to meet the program objectives of sending broadcast turbulence information and the use of VDL–3 to send graphical weather images. This report provides the test requirements and test plans, which led to flight tests, as well as final results from flight testing. The reports define the changes made to both avionics and ground-based receivers as well as the ground infrastructure to support implementation of the recommended architecture, with a focus on the issues associated with these changes.

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WINCOMM

TRANSPORT EN-ROUTE SCENARIO

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TEST REQUIREMENTS

Prepared by: *Russ Jirberg* *10/28/2004*
Russ Jirberg - Lake Logic Systems Date

Approved by: [signature] *10/28/2004*
James Griner - NASA GRC Date
Scenario Lead

Michael G. Jarrell *10/28/2004*
Michael Jarrell - NASA GRC Date
WINCOMM Level III Project Mgr.

REVISION HISTORY

DOCUMENT: WINCOMM Transport En-Route Scenario Test Requirements

FILE NAME: TransportTestRqmts_v1.doc

REV	DATE	DESCRIPTION OF CHANGE
1.0	10/28/04	Initial release

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1.0 Overview

Contained herein are the test requirements for the WINCOMM Transport En-route Scenario. The requirements set forth in this document comprehensively define the objectives and scope of the lab and flight tests for the transport en-route scenario. Based on these requirements, and these requirements alone, formal test plans shall subsequently be formulated and approved that will define the actual tests and test procedures.

The WINCOMM Transport En-route Scenario test program shall demonstrate and evaluate the ability of two digital aviation data links to carry weather data products. One is the 1090 MHz extended squitter (1090ES) data link as defined by the RTCA MASPS and MOPS documents DO-242A and DO-260A, respectively. The 1090ES data link is seen as an effective means of exchanging turbulence alerts between transport aircraft in real time while en-route. The other is the VDL mode-3 (VDLM3) data link as defined by the RTCA MASPS and MOPS documents DO-224A change 1 and 2, and DO-271B, respectively. The VDLM3 data link is seen as an effective means of uplinking and downlinking weather information between the aircraft and the ground, namely (a) the downlinking of turbulence data messages from transport aircraft while en-route to ground data collection centers, (b) the downlinking of pilot-initiated requests for weather data products from aircraft in-flight to ground-based data servers, and (c) the uplinking of textual and graphical weather products from ground servers to transport aircraft while en-route.

The air-to-air turbulence alerts shall be carried in the payload of the 1090 MHz extended squitters and shall be periodically broadcast in accordance with the 1090ES protocols and procedures as established by the above-mentioned RTCA documents. The air-to-air data transfers shall therefore occur on a best-efforts (i.e. unreliable) basis. The air-to-gnd transmission of the turbulence data messages and pilot-initiated weather data requests shall be occur as reliable data transfer using the TCP/IP network protocol in conjunction with the standard VDLM3 protocols and procedures. The weather data products on the other hand shall be uplinked to the aircraft as UDP based broadcasts, again within the framework of standard VDLM3 messaging protocols and procedures.

The test program shall focus exclusively on the data handling aspects of the 1090ES and VDLM3 data links. It shall not focus on matters related to the generation, display, nor the utility of the message data. Consequently, the test program shall justifiably employ the use of prerecorded messages and data products to simulate the actual messages in form and function. Furthermore, the test program shall not focus on the in-space waveforms per se of the 1090ES and VDLM3, i.e. on their rf performance characteristics and limitations. However, signal quality related factors including rf signal levels and link error recovery activity as well as aircraft altitude, attitude, and position shall be monitored (i.e. logged) during testing as supplemental test data so that any occurrences of poor link performance may be properly attributed to degraded link conditions.

It should be noted that the equipment resources for the 1090ES and VDLM3 data links are not interdependent; neither are the messaging requirements for these data links. Therefore, separate test plans shall be generated: one for 1090ES testing and another for VDLM3 testing. Testing

shall be conducted to verify that turbulence and weather data products can indeed be carried onthese data links without causing a disruption to the flow of other traffic that could co-exist on the links. This would include any ADS-B traffic that is likely to be present on the 1090 MHz data link. Similarly, it would include any CPDLC traffic that is likely to use the VDLM3 data link. Thus, the primary objectives of the test program shall be to:

1. Assess the performance characteristics of the 1090ES and VDLM3 data links as pertains to errored messages, message reliability (i.e. lost messages), and message delivery latencies.

2. Assess the ability of TCP/IP and UDP/IP messaging protocols to effectively network the aircraft with the ground server for the transmission of turbulence and weather data message types over the VDLM3 data links.

3. Determine to the maximum extent possible within the limitations of the physical resources available to the test program, what degradations in system performance might result from channel loading, channel congestion, and rf interference effects.

2.0 1090ES Testing

2.1 1090ES Flight System

The 1090ES flight tests shall be conducted using two aircraft, each equipped as indicated in Figure 1. The aircraft shall be equipped to transmit and receive 1090 MHz squitters as specified in RTCA MASPS document DO-242A. Turbulence Test Alert (TTA) messages shall be periodically generated by the airborne computer and sent to 1090ES transmitter. These outgoing TTA messages shall be inserted into the payload portion of the extended squitter by the transmitter and broadcast with minimal delay. The messages shall be squittered on a non-addressed basis in accordance with the ADS-B protocol procedures as proscribed in the above referenced RTCA documents. Incoming TTA messages shall be extracted from the receive squitters and forwarded to the on-board computer via an ethernet LAN interface.

Receive signal quality parameters generated by the 1090 MHz receiver shall be forwarded to the airborne computer via the ethernet interface. These parameters shall include the receive signal level and error status.

The airborne computer shall serve both as a data generator and as the flight data logger. It shall perform the following functions:

(a) Periodically generate the outgoing TTA messages as per Section 2.2, and send them to the 1090ES transmitter,

- continued -

(b) Log and display the incoming and outgoing TTA messages,

(c) Log and display the signal quality parameters output from the 1090ES receiver, and

(d) Log and display the flight sensor data.

The data logs shall be time stamped and recorded as specified in Section 2.3.

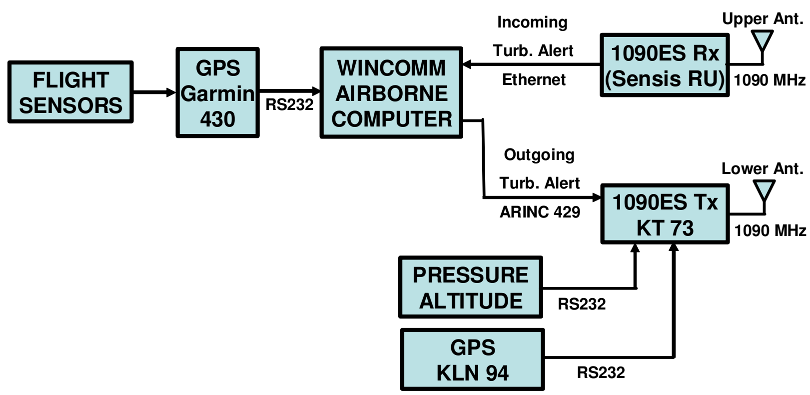

Figure 1. Commercial Transport 1090 ES Airborne System

2.2 Turbulence Test Alert (TTA) message

The turbulence test alert (TTA) messages shall be 16 bits in length. The TTA message shall consist of one 16-bit integer which shall represent the message number. The message number shall be sequentially incremented with each transmission.

The outgoing TTA messages shall be generated and passed to the 1090 MHz transmitter at a nominal rate of once-per-minute. The rate shall be "front panel" adjustable to allow the flight operator to set the message interval within the range of 5 to 60 seconds.

The outgoing TTA messages shall be transferred from the airborne computer to the transmitter via an ARINC 429 interface. The successful transmission of the outgoing TTA messages shall be echoed back to the airborne computer. TTA messages issued by the airborne computer not receiving a confirmation echo within 5 seconds shall be immediately re-issued with the same message sequence number.

2.3 1090ES Event Logs

The on-board computer shall maintain an event log of the data messages, the link parameters, and the flight parameters throughout the test flights. All events shall be time and date stamped. The events shall include the following:

(a) Incoming and outgoing TTA messages,
(b) Receive signal quality,
(c) Errored and discarded messages, and
(d) Aircraft position, altitude, and heading

The file format of the event log is **TBD**.

2.4 1090ES Ground Segment

The 1090ES testing shall be conducted exclusively via the air-to-air data links. No ground based equipment shall be required.

2.5 1090ES Test Flight Profiles

The test flights shall be conducted under straight and level conditions. The two aircraft shall fly essentially parallel flight paths at approximately the same altitude. The operational separation of the two aircraft during testing shall not exceed 75 nmi.

3.0 VDLM3 Testing

VDLM3 testing shall be conducted using the NASA Glenn LearJet 25 research aircraft in conjunction with the FAA ground station located at FAA Technical Center in Atlantic City, New Jersey. The system shall be configured to use one data channel of a 2V2D configuration. Indicated in Figure 2 are the airborne and ground segments of the VDLM3 test system.

3.1 VDLM3 Flight Segment

The VDLM3 radio shall operate in full compliance with the protocols and procedures for VDLM3 communications as defined in RTCA MASPS and MOPS documents DO-224A change 1 and 2, and DO-271B, respectively. The flow of messages in and out of the radio shall be managed by the Communications Management Unit (CMU). Incoming textual and graphical data products shall be displayed on the IDC 900. The IDC 900 shall also serve as the operator interface for the retrieval of the weather data products and for the issuance of weather data product requests. Supplemental I/O to and from the CMU shall include an ARINC 429 interface to input GPS time and position information,

and a RS-232 port to interface the link protocol parameters to the airborne computer. Link performance parameters from the radio shall be sent to the airborne computer, also through an RS-232 interface.

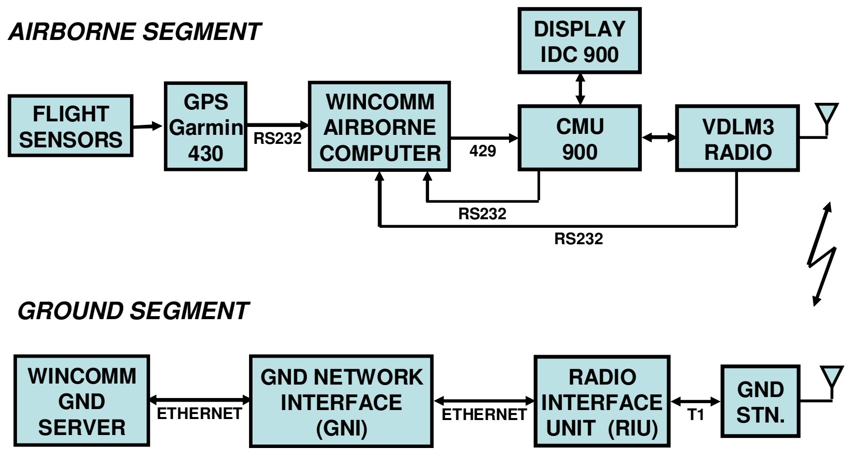

Figure 2. Commercial Transport VDLM3 Airborne and Ground Systems

The airborne computer shall serve as both a Turbulence Test Message (TTM) generator and as a flight event/data logger. The TTM shall be generated as specified in Section 3.3.1 and transferred to the CMU via an ARINC 429 interface using the Williamsburg v1 protocol. The individual TTMs shall be logged in the airborne computer along with the flight data from the flight sensors and the signal quality parameters from the radio. The content and format of the flight event/data log shall be as specified in Section 3.4.

The CMU shall be assigned the IP address 192.168.1.2.

3.2 VDLM3 Ground Segment

The VDLM3 ground segment shall consist of the FAA ground station together with a NASA supplied WINCOMM Gnd Server as indicated in Figure 2. The FAA shall provide an ethernet interface to its Ground Network Interface (GNI) subsystem. The interface shall conform to the FAA-NASA ICD, reference document 5.1. The individual Weather Test Product (WTP) APDUs as defined in RTCA DO-267 shall exist as static files within the WINCOMM Gnd Server. NASA shall provide the client/server software that will reside in the WINCOMM Gnd Server. An NTP connection shall provide an accurate and stable time base.

The WINCOMM Gnd Server shall constitute the server portion of a TCP/IP client/server network architecture. It shall perform the following functions:

(a) Log and display the TTM transmitted to the ground from the aircraft,

(b) Maintain the WTP APDU files for uplinking to the aircraft,

(c) Issue on a periodic basis WTP files for broadcast from the *standard* set of textual and graphical weather data products as indicated in Section 3.3.3,

(d) Issue operator-requested WTP files for broadcast from the *request* set of graphical weather data products as indicated in Section 3.3.3,

(e) Log and display the issuance of all (both *standard* and *request*) WTP files, and

(f) Log and display the Weather Request Messages.

The WINCOMM Gnd Server shall be assigned the IP address 192.168.1.1.

3.3 VDLM3 Messages

3.3.1 Air-to-Gnd Turbulence Test Message (TTM)

The Turbulence Test Message (TTM) shall be generated by the airborne computer. It shall be transferred to the CMU via an ARINC 429 interface using the Williamsburg v1 protocol. The TTM shall be transmitted to the ground in accordance with the VDLM3 protocols procedures as specified in RTCA MASPS document DO-224A.

The TTM shall be 77 bytes in length. The TTM shall contain the following comma-delimited fields:

Byte No.	Length	Contents	Description
1 – 12	12	$TURBULENCE,	Start of message
12 – 25	13	hh:mm:ss.sss,	Timestamp
26 – 31	6	nnnnn,	Sequence no.
32 – 75	44	ASCII text string	Free text message
76 – 77	2	ASCII c/r and l/f	End of message

Notes:

1. The timestamp shall be the UTC time of generation of the message; the resolution shall be one millisecond.

2. The sequence number shall start at 00001 and increment by one with each message sent. It shall roll over from 99999 back to 00001.

3. The 44-byte free text message shall be generated by the operator in real time via the airborne computer. Unused characters shall default to the underscore character (ASCII 0x5F).

4. Example messages:

```
Byte     1         2         3         4         5         6         7
12345678901234567890123456789012345678901234567890123456789012345678901234567

$TURBULENCE,09:19:51.000,00123,____________________________________________crlf
$TURBULENCE,09:20:51.000,00124,This is a free text message.________________crlf
```

The TTM shall be generated and transmitted at a nominal rate of once per minute. The rate shall be “front panel” adjustable to allow the flight operator to set the message interval within the range of 5 to 60 seconds.

The CMU shall forward the TTM as a TCP/IP v4 client to the ground server. The TCP Destination port for the TTM messages shall be 11502. The TCP connections once established shall be maintained.

3.3.2 Air-to-Gnd Weather Data *Requests*

Weather product R*equest* messages shall be transmitted from in-flight test aircraft to the ground in accordance with the VDLM3 protocol procedures as specified in RTCA MASPS document DO-224A. The *Request* messages shall be manually initiated on-board the test aircraft via a key press (or series of key presses) on the IDC. The selectable weather test products (WTPs) shall be those listed in the *Request Set* of Appendix A.

The content and format of the *Request* message shall be as specified in Section 6.2.2 of Reference Document 5.2.

The CMU shall issue the *Request* messages as a TCP/IP v4 client to the ground server. The TCP Destination port for the *Request* messages shall be 11503. The TCP connections once established shall be maintained for 2 minutes in the absence of message traffic on the connection.

3.3.3 Gnd-to-Air Weather Test Products (WTP)

The ground station shall be capable of transmitting a variety of weather textual and graphical test products (WTP) as specified in Appendix B. Two categories of WTPs are indicated: a *standard* set and a *request* set. WTP from the *standard* set shall be issued

with a higher priority of transmission than those from the *request* set. All WTP files shall be compressed using the *Deflate* file compression algorithm.

The entire set of *standard* WTP shall be broadcast at 5-minute intervals throughout the test flights. WTP from the *request* set shall be transmitted once per request on an as-time-available basis. The WINCOMM Gnd Server shall issue the WTP files to the GNI of the ground station on a time scale consistent with the rate at which they are capable of being transmitted over the VDLM3 uplink. A channel utilization margin of nominally 25% shall be allocated to allow for the transmission of other digital data messages that may be assigned to the same data link (e.g. CPDLC messages). The WINCOMM Gnd Server shall queue the requested WTP for transfer to the GNI so as to preserve that unused channel margin.

The WINCOMM Gnd Server shall transfer the WTP files to the GNI as UDP IP datagrams. The files shall be broadcast using IP address 192.168.1.2, port number 11501. The IP parameters and fields shall be set as follows:

(a) IP version:	4	
(b) Type of service, precedence bits:	2	for high priority *standard* WTPs
	1	for low priority *request* WTPs
(c) Time-to-live:	1	
(d) Protocol:	17	(UDP)
(e) IP data payload:	WTP file in *Deflate* compressed form.	

Large WTPs shall be segmented at the IP layer. The datagram MTU shall be 922 bytes. Each segment shall include a 1-byte IPI (0xCC = IPv4).

3.4 VDLM3 Flight Logs

The airborne computer shall maintain an event log of the data messages link parameters, and flight parameters throughout the test flights. The events shall include the following:

(a) All TTMs
(b) All *Request* messages
(c) All WTPs
(d) Receive signal level as issued by the radio
(e) Aircraft position, altitude, and heading

All events shall be date and time stamped. In addition, a supplemental written flight log shall be maintained by the test operator. The written log shall document pertinent comments and observations of the operator as deemed appropriate.

3.5 VDLM3 Ground Server Logs

The WINCOMM Gnd Server shall maintain an event log of all message traffic it issues and all messages it receives. The events shall include the following:

(a) All TTMs
(b) All *Request* messages
(c) The file name of all WTPs transmitted
(d) The connect and disconnect times for all TCP sessions

All events shall be date and time stamped. In addition, a supplemental written log shall be maintained by the ground test operator. The written log shall document pertinent comments and observations of the operator as deemed appropriate.

3.6 VDLM3 Test Flight Profiles

The test flights shall be conducted under straight and level conditions at altitudes in the range of 5,000 to 40,000 MSL. The test aircraft shall fly both radial and crossing (i.e. fly-by) patterns within the known operational range of the FAA ground station.

4.0 Lab Testing

Lab tests shall be conducted in advance of the flight tests. The testing shall be conducted for the purpose of:

(a) Verifying the functionality of the 1090 and VDLM3 flight equipment,
(b) Verifying the interoperability of the air-to-air (1090ES) systems,
(c) Verifying the TTA message formats,
(d) Verifying the functionality WINCOMM Gnd Server software,
(e) Verifying the interoperability of the WINCOMM Gnd Server with the GNI,
(f) Verifying the interoperability of the VDLM3 airborne and ground segments,
(g) Verifying the TTM message formats and the TCP message exchange processes,
(h) Verifying the WTP datagram formatting, segmentation, and re-assembly,
(i) Verifying the airborne and ground data log structure and operation, and
(j) Establishing operational proficiency with the flight and ground systems.

The lab tests shall be accomplished in a non-radiating mode; i.e. all rf interconnections shall be made using coaxial cables and appropriately sized attenuators.

5.0 Reference Documents

5.1 VDL Mode 3 Ground Network Interface (GNI) IP Gateway Interface Control Document, FAA-NASA-ICD-01, version 0.5, September 1, 2004.

5.2 Software Requirements Specification (SRS) for the CMU-900 Weather Aircraft Operational Communications Application (AOC)
Rockwell Collins document CPN xxx-xxxx-001 issued August 12, 2004.

APPENDIX A

Weather Data Products (WDPs)

Standard Set

Textual	Product Identifier
Aviation Routine Weather Reports (METARs) Combined with Special Aviation Reports (SPECIs)	0
Terminal Area Forcasts (TAFs) and their amendments	1
Significant Meteorological Information (SIGMETs)	2
Convective SIGMETs	3
Airman's Meteorological Information (AIRMETs)	4
Pilot Reports, both urgent and routine (PIREPs)	5
Severe Weather Forecast Alerts (AWWs)	6

Graphical	
NEXRAD national, 10 kilometer resolution Region: 0M, Product: 01	401
Cloud Tops / Echo Tops Region: 0M, Product: 02	401

- continued -

Weather Data Products (WDPs) --- Continued

Request Set

Textual	Product Identifier
(none)	

Graphical	Product Identifier
NEXRAD regional, 10 kilometer resolution Regions: 0V, 0W, 0Z, Product: 01	401
Icing Region: 0M, Product: 06 Flight Levels: 24, 30, 34 Forecast Time: 00	401
Turbulence Region: 0M, Product: 05 Flight Levels: 24, 30, 34 Forecast Time: 00	401
Wind / Temp Aloft Region: 0M, Product: 04 Flight Levels: 24, 30, 34 Forecast Time: 00	401

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WINCOMM

TRANSPORT EN-ROUTE SCENARIO

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VDL MODE 3
TEST PLAN

Prepared by: Russ Jirberg 3/31/05

Russ Jirberg - Lake Logic Systems Date

Approved by: 3/31/05

James Griner - NASA GRC Date
Scenario Lead

Michael A. Jarrell 3/31/05

Michael Jarrell - NASA GRC Date
WINCOMM Level III Project Mgr.

REVISION HISTORY

DOCUMENT: WINCOMM Transport En-Route Scenario
VDL Mode 3 Test Plan

FILE NAME: TransportTestPlan_VDLM3_v1.doc

REV	DATE	DESCRIPTION OF CHANGE
0.0	11/09/04	Draft
1.0	3/31/05	Initial release.

TABLE OF CONTENTS

1.0 Overview

Contained herein is the test plan for the validation and demonstration of the VDL mode 3 (VDLM3) digital data link as a means of providing weather data and turbulence data to and from transport aircraft in real time while en-route.

1.1 Test Requirements

The requirements for the WINCOMM VDLM3 data link test program are contained within the WINCOMM Transport En-Route Scenario Test Requirements document (Reference document 8.1).

1.2 Test Objectives and Approach

The purpose of the VDLM3 test program is to establish the effectiveness of VDLM3 digital data links as a communications technology for sending turbulence data from in-flight transport aircraft to weather data collection centers on the ground, and for uplinking weather data, both textual and graphical, from the ground to in-flight transport aircraft. It is not the purpose of the test program to evaluate the effectiveness of the data transmitted over the VDLM3 links from an operational standpoint, nor is it the purpose of the test program to address the man-machine related considerations of the data of the air or ground data displays. The testing thus shall be conducted using canned data products that simulate in form and function the actual turbulence and weather data products that might eventually be carried operationally on these links.

The flight test program shall be conducted by NASA in conjunction with its Project partners. One research aircraft shall be outfitted as indicated in Figure 1. The airborne avionics and displays shall be commercially available units. Software modifications shall be made to these units as necessary to provide the capabilities specified in the test requirements (Reference document 8.1). The test flights shall be conducted in cooperation with the FAA using the VDLM3 ground station located at the FAA Technical Center in Atlantic City, New Jersey. NASA shall provide the ground server computer and software, which will interface to the GNI subsystem of the VDLM3 ground station. The flight tests shall follow flight profiles that will serve to demonstrate and evaluate the communications aspects of the VDLM3 technology as prescribed herein.

The testing shall be completed in phases. The first phase shall consist of the laboratory functional tests associated with the development or modification of the individual airborne and ground subsystems. These tests shall be conducted separately by each project partner at their own facilities. The second phase shall consist of the system level functional test associated with the integration of the flight system and ground system, and the verification testing of their interoperability. These tests shall be conducted jointly at the FAA Technical Center. The testing shall involve the FAA's VDLM3 ground station to provide a VHF link between the airborne and ground

segments. The RF interconnect shall be cabled (i.e. non-radiating). The third phase shall consist of the flight tests using the NASA aircraft in conjunction with the FAA's ground station. Formal test procedures and checklists shall be generated and followed for both the airborne and ground segments when conducting the flight tests.

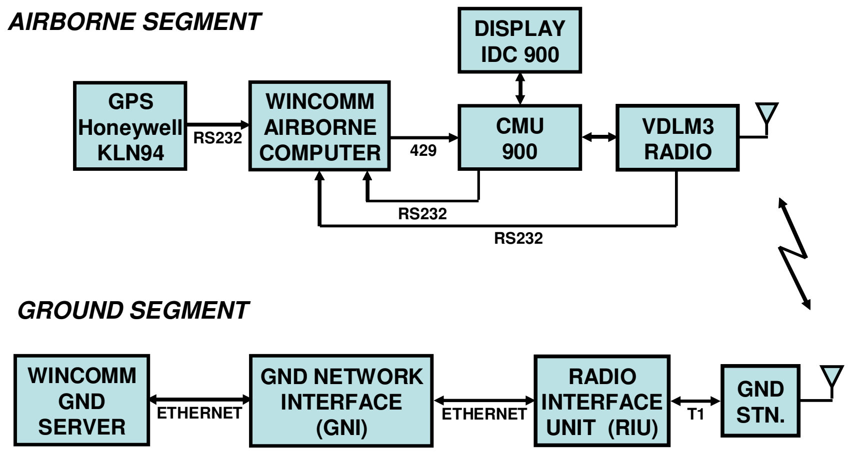

Figure 1. Commercial Transport VDLM3 Airborne and Ground Systems

1.3 Participants

NASA shall be responsible for the overall project management, for the preliminary integration and testing of the airborne hardware and software, for the ground server, for the test flights, and for the subsequent data analysis and reporting. Rockwell Collins shall be responsible for the software design modifications that are required to the CMU and display unit. Rockwell Collins shall also participate in the overall system design, and shall provide technical support during the system integration and ground testing as well as the follow-on flight tests. The FAA shall be responsible for the design and implementation of the Ground Network Interface (GNI). In addition, the FAA shall participate in the overall system design, and shall provide operational support during the system integration and ground testing activities as well as the follow-on flight tests.

2.0 Laboratory Tests

Laboratory testing of the airborne and ground subsystems shall be performed prior to the integration and testing at the system level. Functional verification testing of the avionics and display units shall be conducted by Rockwell Collins prior to the delivery of those units to NASA. Similarly, the FAA shall verify the compatibility and message handling capability of the

ground server interface. NASA shall develop and test the software that will reside in the airborne and ground server computers. NASA shall also provide the computer for the ground server as well as the computer, equipment racks, ancillary equipment, cabling, and installation of the airborne segment. The laboratory testing shall specifically include the following subsystem-level tests.

2.1 WINCOMM Airborne Computer (WAC) Subsystem Tests.

The test operator shall follow the procedures outlined in the VDLM3 Operations document (Reference document 8.3) in setting up the VDLM3 airborne system as well as the VDLM3 ground system. The operator interface screen of the *WAC* program provides the operator with the necessary visibility into the operational status of the Williamsburg data transfers from the WAC to the CMU. The interface screen also provides the means for the operator to synchronize the system (i.e. WAC) clock to a GPS time signal, to adjust the message timing, and to observe the message history. The test operator shall perform functional tests to verify the format, content, and timing, as appropriate, of the following data messages:

2.1.1 Turbulence Test Message (TTM).

This test shall be performed using the *WAC* LabVIEW program, which manages the ARINC 429 based data communications between the WAC computer and the CMU. These data transfers are implemented in accordance with the Williamsburg (version 1) bit-oriented file transfer protocol as defined in Reference document 8.2. The program simulates the transference of TTM message files. Each TTM contains a 77-byte data field as defined in the WINCOMM Transport En-Route Scenario Test Requirements document (Reference document 8.1), and a 5-byte ARINC 619 accountability header. The test operator shall verify the following operational capabilities:

2.1.1.1 WAC to CMU data communications.

By observing the progression of status and error messages provided on the interface screen, the test operator shall verify that WAC program successfully establishes communications with the CMU for the Williamsburg 429 based data transfers. The operator shall also verify that the re-linking process, which re-establishes the Williamsburg protocol communications, is functional.

2.1.1.2 TTM file transfer.

The operator shall verify that WAC program successfully generates TTM's on an interval-adjustable basis. Additionally the operator shall verify (1) that free text messages can be inserted into the TTM's, (2) that individual messages can be sent on an immediate basis, and (3) that the timed messaging can be inhibited while at the same time allowing individual messages to be transmitted on an immediate basis.

2.1.1.3 TTM message history.

The test operator shall verify that the TTM's sent to the CMU register in order on the interface screen.

2.1.1.4 GPS time synchronization. With the KLN94 GPS receiver active, the operator shall verify that the system clock can be synchronized to the GPS to within 1 second.

2.1.1.5 Log file. The test operator shall verify that the *WAC* program is consistently logging the TTM's issued to the CMU with the correct time stamp, message format, and message content.

2.1.2 VDLM3 radio trace port messages. This test shall be performed using the Rockwell Collins terminal emulator, *debugmon.exe*. The test operator shall verify that the parameters from the VDLM3 radio are being received and displayed on the computer monitor, and that the data log is being properly generated.

2.1.3 CMU maintenance port messages. This test shall be performed using a terminal emulator application such as *TeraTerm*. The test operator shall verify that the parameters from the CMU maintenance port are being received and displayed on the WAC monitor, and that the data log is being properly generated.

2.1.4 ICAO address. The test operator shall verify (1) that the appropriate GPS data is being received and displayed on display unit (IDC 900), (2) that the *XPDR1 status* under the *Peripheral Status* menu changes from *ABSENT* to *PRESENT*, and (3) that the ICAO address sent to the CMU appears under the *ACARS* menu on the display unit (IDC 900).

2.1.5 GPS and flight parameter data. With the KLN94 GPS active, the test operator shall verify that the latitude, longitude, ground speed, and altitude data is being received and displayed on the display unit (IDC 900), and that the *GPS status* under the *Peripheral Status* menu changes from *ABSENT* to *PRESENT*.

2.2 WINCOMM Ground Server Subsystem Tests. Functional testing shall be performed to verify the format, content, and timing, as appropriate, of each function the server performs. These tests shall be performed using test client programs that simulate the actual messages that the server will receive.

In preparation for this testing, the test operator shall confirm that the registry edit, MTU change, and clock synchronization setting described on the *About* tab have been performed. Secondly, the test operator shall confirm that the system variables, IP addresses, and port numbers that appear on the *System Parameters* tab are set to their predetermined values. Upon starting the server program, the test operator shall verify that the GNI Port LED and GNI Ready LEDs are lit, and that the *Enable/Inhibit* switch on the *Outgoing Messages* tab is in the *Enable* position.

The specific tests shall be as follows:

2.2.1 Turbulence Test Message (TTM). This test shall be performed using a test client that generates simulated TTM messages. The test operator shall verify that the simulated TTM messages appear sequentially on the *Turbulence Messages* tab with the correct content and format. The test operator shall also verify that client will automatically connect to the server.

2.2.2 WTP *request* message. This test shall be performed using a test utility that generates simulated WTP *request* messages. The test operator shall verify that the simulated WTP *request* messages appear sequentially on the *Product Requests* tab with the correct content and format. The test operator shall verify that the server will disconnect from the client after the set idle time, and that the client will automatically reconnect with the resumption of message traffic.

2.2.3 WTP ADPUs, both *standard* and *request*. This test shall be performed using a representative set of ADPUs that simulate actual WTPs. The test operator shall verify that the file names of the simulated WTPs appear sequentially on the *Outgoing Messages* tab with the proper timestamps. In the process, the test operator shall verify that the WTPs are issued in accordance with the intended timing and sequencing. The test operator shall also verify that the WTP *request* queue functions properly, and that the issuance of the outgoing WTPs responds properly to the *Enable/Inhibit* switch on the *Outgoing Messages* tab. Finally, the test operator shall verify that the ADPU files are properly fragmented and encapsulated into IP datagrams using the *Ethereal* network protocol analyzer.

2.2.4 IP message prioritization. The test operator shall verify that the TOS bits in the IP headers of the *standard* and *request* WTPs are properly set by direct examination of the IP header using the *Ethereal* network protocol analyzer.

2.2.5 GNI flow control. This test shall be performed using a test utility program that simulates the GNI flow control messages. The test operator shall verify that the flow of outgoing messages ceases when the *inhibit* command is received, and that the flow resumes when the *resume* command is received.

2.2.6 Log files. The test operator shall stop the server program and examine each of the log files to verify their content and format. The test operator shall also verify that, when restarted, the program appends new data to the end of the existing log files, and that when the log files are deleted (or moved), the program creates new files in their place.

3.0 System Integration and Ground Testing

Upon completion of the laboratory testing (Section 2.0), the airborne system components shall be integrated in preparation for system-level testing at the FAA Technical Center in Atlantic City, New Jersey. Concurrently, the ground server shall be integrated into the FAA's

VDLM3 ground station. The ground station shall provide the VDLM3 link between the airborne segment and the ground server. During the initial ground test (i.e. Ground Test #1), the RF interconnect between the airborne radio and the ground station shall be cabled (i.e. non-radiating). A second ground test (Ground Test #2) shall be conducted wherein the RF link between the airborne and ground segments shall be active (i.e. radiating on-air).

The purpose of the ground testing is to verify that the airborne and ground segments are mutually interoperable and fully functional. The following specific system-level tests shall be performed in conjunction with the VDLM3 ground station. The test operator(s) shall follow the procedures outlined in the VDLM3 Operations document (Reference document 8.3).

3.1 Airborne Subsystem Testing. Tests shall be performed to verify the subsystem interconnects (i.e. cabling and pin-outs) are compatible and functional. The specific tests shall include the following:

3.1.1 Subsystems interconnects, power supply voltages, and tuning panel. The test operator shall verify that (1) the subsystem interconnects (i.e. cabling and pin-outs) are properly configured, (2) the power supply voltages are properly set, (3) the tuning panel is functional, and (4) all RF cables are properly connected/ terminated.

3.1.2 TTM TCP connection. The test operator shall verify that the CMU can establish a TCP connection with the TTM port on the ground server.

3.1.3 TTM transmission. The test operator shall verify that the WAC is generating TTM's and transferring those messages to the CMU, and that the CMU in turn transmits those messages to the ground station.

3.1.4 WTP *Request* TCP connection. The test operator shall verify that the CMU can establish a TCP connection with the WTP *request* port on the ground server.

3.1.5 Uplinked WTP reception and display. The test operator shall verify that the standard and request WTP sent from the ground server via the ground station are received and properly displayed on the display unit (IDC 900).

3.1.6 Airborne event / message log. The test operator shall verify that the uplinked WTP headers are logged on the WAC along with the correct time stamp.

3.1.7 VDLM3 Voice Channel Communications. The test operator shall confirm that the voice channel of the VDLM3 2V2D configuration is functional. Tests shall be conducted using push-to-talk microphones.

3.1.8 VDLM3 Radio Trace Port Message. This test shall be performed using the Rockwell Collins terminal emulator, *debugmon.exe*. The test operator shall verify that the parameters from the communications port of the VDLM3 radio are being received and displayed on the WAC monitor.

3.1.9 CMU Maintenance Port Message. This test shall be performed using a terminal emulator application such as TeraTerm. The test operator shall verify that the parameters from the CMU maintenance port are being received and displayed on the WAC monitor.

3.1.10 ICAO Address. This test shall be performed as described in Section 2.1.4.

3.1.11 GPS data. This test shall be performed as described in Section 2.1.5.

3.2 WINCOMM Ground Server Testing. Functional testing shall be performed to verify that the server - GNI interconnect is operational, and that message formats, content, and timing, as appropriate, are correct.

In preparation for this testing, the test operator shall confirm that the registry edit, MTU change, and clock synchronization setting described on the *About* tab have been performed. Secondly, the test operator shall confirm that the system variables, IP addresses, and port numbers that appear on the *System Parameters* tab are set to their predetermined values. Upon starting the server program, the test operator shall verify that the GNI Port LED and GNI Ready LEDs are lit, and that the *Enable/Inhibit* switch on the *Outgoing Messages* tab is in the *Enable* position.

The specific functional tests that are to be performed are as follows:

3.2.1 TTM TCP connection. The test operator shall verify that the airborne computer can automatically connect to the server, and will automatically reconnect following restoration of the link following a simulated loss of signal.

3.2.2 WTP request message TCP connection. The test operator shall verify that the CMU can automatically connect to the server, and will automatically reconnect following restoration of the link following a simulated loss of signal. Additionally, the test operator shall verify that server will automatically cause a disconnect after the prescribed idle period.

3.2.3 Reception of Turbulence Test Messages (TTM). This test requires the airborne segment to establish a TCP connection with the server, and to send a series of TTMs. The test operator shall verify that *Turb Port* LED is lit, and that TTM messages are appearing on the *Turbulence Messages* tab. In addition, the test operator shall verify that the TTMs have the correct content and format, and are properly time stamped.

3.2.4 Reception of WTP *request* messages. This test requires the airborne segment to establish a TCP connection with the server, and to send a series of WTP *request* messages. The test operator shall verify that *REQ Port* LED is lit, and that WTP *request* messages are appearing on the *Product Requests* tab. In addition, the test

operator shall verify that the messages have the correct content and format, and are properly time stamped.

3.2.5 Issuance of *standard* and *request* WTP uplink ADPUs. The test operator shall verify that ADPU files are issued to the GNI as indicated on the *Outgoing Messages* tab. Concurrently, reception of the WTPs by the airborne segment shall be confirmed. As the WTPs are issued, the test operator shall confirm that the flow of WTPs is interrupted in accordance with the GNI flow control status.

3.2.6 Verification of UDP message priorities. The test operator shall verify that the IP headers for the *standard* and *request* WTP ADPUs contain the correct TOS bits. This test shall be accomplished with the aid of the *Ethereal* network protocol analyzer.

3.2.7 Verification of UDP fragmentation. The test operator shall verify that the maximum size of the uplink UDP datagrams sent to the GNI does not exceed the prescribed value as specified on the *About* tab. This test shall be accomplished with the aid of the *Ethereal* network protocol analyzer.

3.2.8 Verification of the log files. The test operator shall stop the server program and examine each of the log files to verify their content and format.

4.0 Aircraft Installation and Checkout

Upon completion of the ground tests (Section 3.0), the airborne system shall be installed on the NASA LearJet 25. During this installation at the Glenn Research Center, the functionality of the system shall be verified by connecting the airborne equipment to the FAA-provided ground station. This testing shall be accomplished using cabled (i.e. non-radiating) interconnects. The purpose of these tests shall be to verify prior to the start of flight testing that the airborne system is fully functional as it is installed in the aircraft.

5.0 Ramp Testing

Upon completion of the installation and checkout of the airborne system in the aircraft (Section 4.0), the aircraft shall be relocated to the Atlantic City airport. The ground server shall be relocated to the FAA Technical Center and re-integrated with the FAA's VDLM3 ground station. The functionality of the system shall be re-established using an active (i.e. on-air) VDLM3 channel between the airborne and ground segments. During ramp testing, the airborne equipment shall be powered from *ground* power. The purpose of these tests shall be to verify that the system, including the radio and antenna, is fully functional in preparation for the start of flight testing.

The ramp tests shall be a subset of the flight test. They shall provide verification of the following test instrumentation, voice communications links, and GPS operation:

(1) VDLM3 data link (aircraft - ground station Tx/Rx VDLM3 radio links),
(2) TTM message generation, text messaging, and logging,
(3) *Request* WTP message generation and logging,
(4) Reception, display, and logging of uplinked WTPs,
(5) VDLM3 voice channel communications,
(6) Iridium satellite voice communications (as a backup voice channel), and
(7) GPS time and location message generation.

6.0 Preflight Testing

Preflight tests shall be conducted prior to each test flight. These tests shall be conducted with the aircraft on the ramp with the engines running. The airborne equipment shall be powered-on using ship-board power. System-level tests shall be executed prior to take-off to verify the following functions:

(1) Functionality of the VDLM3 avionics, ancillary equipment, and computer software,
(2) Operation of the VDLM3 voice channel communications,
(3) Operation of the VHF AM voice channel as a communications backup, and
(4) Operation of the GPS.

All systems must be fully functional as a condition for take-off.

7.0 Flight Testing

The test flights shall be conducted in coordination with the FAA Technical Center in Atlantic City, NJ. The test flights shall be flown within the coverage area of the ground station located at the FAA Technical Center. The test flights shall be conducted in accordance with the following procedures and objectives.

Two test flights shall be made per day: a morning flight and an afternoon flight. Preflight system tests shall be conducted prior to each Test Flight as indicated in Section 6.0 to verify that all systems are operating and fully functional. Voice coordination with the WGS operator(s) shall be established prior to takeoff using the VDLM3 voice channel and the VHF AM radio.

The WGS shall be configured to broadcast a full set of s*tandard* test products consisting of 7 WTPs, and a full set of r*equest* test products consisting of 14 WTPs as listed in Section 9.0.

During each of the test flights, the airborne and ground test operators shall maintain a written log of the significant events and times to aid in the correlation of the flight data logs with those recorded at the WGS.

7.1 Test Flight #1. Test Flight #1 shall serve as a "dress rehearsal" to the follow-on operational data gathering test flights. The primary objectives of Test Flight #1 are:

(1) to verify the operation of the VDLM3 data communications equipment and software,
(2) to verify the operation of the radio voice communications, and
(3) to evaluate the general flight procedures.

The flight parameters for Test Flight #1 shall be as follows:

7.1.1 Flight pattern. Radial from Atlantic City airport, straight and level at 35,000 feet (nominal), out to the limit of coverage, and return. The airborne operator shall mark the limit of coverage as the point at which the CMU VDL3 Link Status indicates "No Net," indicating a loss of network connectivity. The aircraft shall continue on its out-bound course beyond that point for 3 minutes, in order to test protocol timer expiration, before turn back toward Atlantic City. Flight duration is approximately 1 hour.

7.1.2 Data Communications. TTM's shall be transmitted regularly to the WGS at 60-second intervals. The WGS shall repeatedly broadcast one (and only one) of the s*tandard* WTPs regularly at 10-second intervals. During the test flight the airborne operator shall issue requests for one of two r*equest* WTPs an on alternating basis, at 5-minute intervals. Upon receiving the request, the WGS shall broadcast the requested WTP.

7.1.3 Post Flight Activities. Upon completion of the test flight, the aircraft and ground logs shall be examined to verify the individual data formats, content, and time stamps, and to verify that the aircraft and ground logs can be correlated. A formal debriefing of the flight shall be held with the airborne test operators, ground test operators, and the pilots for the purpose of reviewing the test procedures, the preliminary test results, and to revise as necessary the follow-on flight plans.

7.2 Test Flight #2. Test Flight #2 shall be the first of four operational data gathering flights. The flight parameters for this test flight shall be as follows:

7.2.1 Flight pattern. Two legs, each leg along a radial from the Atlantic City airport out to the limit of coverage and return, straight and level at 35,000 feet (nominal). Flight duration is approximately 2 hours.

7.2.2 Data Communications. TTM's shall be transmitted regularly to the WGS at 60-second intervals. The WGS shall cyclically broadcast the full set of s*tandard* WTPs at 10-second intervals throughout the duration of the test flight. During the second leg *only* of the test flight, the airborne test operator shall issue requests for r*equest* WTPs at 5-minute intervals. The WGS shall broadcast the requested WTPs interspersed in among the s*tandard* WTPs.

7.2.3 Post Flight Activities. Upon completion of the test flight, the aircraft and ground logs shall be examined to verify the individual data formats, content, and time stamps, and to verify that the aircraft and ground logs can be correlated. A formal debriefing of the flight shall be held with the airborne test operators, ground test operators, and the pilots for the purpose of reviewing the test procedures, preliminary test results, and to revise as necessary the follow-on flight plans.

7.3 Test Flight #3. Test Flight #3 shall be the second of four operational data gathering flights. The flight parameters for this test flight shall be as follows:

7.3.1 Flight pattern. Two legs, each leg along a radial from the Atlantic City airport out to the limit of coverage and return, straight and level at 35,000 feet (nominal). Flight duration is approximately 2 hours.

7.3.2 Data Communications. TTM's shall be transmitted regularly to the WGS at 60-second intervals during the first leg of the flight and at 30-second intervals during the second leg. The WGS shall cyclically broadcast the full set of s*tandard* WTPs at 10-second intervals throughout the duration of the test flight. On both legs of the flight the airborne operator shall issue requests for WTPs from the *request* set of WTPs. The requests shall be made at 5-minute intervals during the first leg of the flight, and at 2-minute intervals during the second leg. The WGS shall broadcast the requested WTPs interspersed in among the s*tandard* WTPs.

7.3.3 Post Flight Activities. Upon completion of the test flight, the aircraft and ground logs shall be examined to verify the individual data formats, content, and time stamps, and to verify that the aircraft and ground logs can be correlated. A formal debriefing of the flight shall be held with the airborne test operators, ground test operators, and the pilots for the purpose of reviewing the test procedures, preliminary test results, and to revise as necessary the follow-on flight plans.

7.4 Test Flight #4. Test Flight #4 shall be the third of four operational data gathering flights. The flight parameters for this test flight shall be as follows:

7.4.1 Flight pattern. Two (or three) legs, each leg along a radial from the Atlantic City airport out to the limit of coverage and return, straight and level at 24,000 feet (nominal). Flight duration is approximately 2 hours.

7.4.2 Data Communications. TTM's shall be transmitted regularly to the WGS at 30-second intervals. The WGS shall cyclically broadcast the full set of s*tandard* WTPs at 10-second intervals throughout the duration of the test flight. Concurrently, the airborne test operator shall issue requests for r*equest* WTPs at 2-minute intervals. The WGS shall broadcast the requested WTPs interspersed in among the s*tandard* WTPs.

7.4.3 Post Flight Activities. Upon completion of the test flight, the aircraft and ground logs shall be examined to verify the individual data formats, content, and time stamps, and to verify that the aircraft and ground logs can be correlated. A formal debriefing of the flight shall be held with the airborne test operators, ground test operators, and the pilots for the purpose of reviewing the test procedures, preliminary test results, and to revise as necessary the follow-on flight plans.

7.5 Test Flight #5. Test Flight #5 shall be the fourth of four operational data gathering flights. The flight parameters for this test flight shall be as follows:

7.5.1 Flight pattern. Two (or three) legs, each leg along a radial from the Atlantic City airport out to the limit of coverage and return, straight and level at 24,000 feet (nominal). Flight duration is approximately 2 hours.

7.5.2 Data Communications. TTM's shall be transmitted regularly to the WGS at 15-second intervals. The WGS shall cyclically broadcast the full set of s*tandard* WTPs at 10-second intervals throughout the duration of the test flight. Concurrently, the airborne test operator shall issue requests for r*equest* WTPs at 1-minute intervals. Additionally at one point during the second leg of the flight, the airborne operator shall issue a series of requests in rapid succession for each of the *request* WTPs as a channel loading test. The WGS shall broadcast the requested WTPs interspersed in among the s*tandard* WTPs.

7.5.3 Post Flight Activities. Upon completion of the test flight, the aircraft and ground logs shall be examined to verify the individual data formats, content, and time stamps, and to verify that the aircraft and ground logs can be correlated. A formal debriefing of the flight shall be held with the airborne test operators, ground test operators, and the pilots for the purpose of reviewing the test procedures and the preliminary test results.

8.0 Reference Documents

8.1 WINCOMM Transport En-Route Scenario Test Requirements, v1.0, dated 10/28/04.

8.2 ARINC Specification 429P3-18, Mark 33 Digital Information Transfer System (DITS), Part 3, File Data Transfer Techniques, October 12, 2001.

8.3 VDLM3 Operations. Operational procedures for the VDLM3 aircraft and ground systems. March 1, 2005.

8.4 VDL Mode 3 Ground Network Interface (GNI) IP Gateway Interface Control Document, FAA-NASA-ICD-01, version 0.5, September 1, 2004.

8.5 Software Requirements Specification (SRS) for the CMU-900 Weather Aircraft Operational Communications Application (AOC)
Rockwell Collins document CPN xxx-xxxx-001, issued August 12, 2004.

9.0 ADPU Test Products

9.1 Standard Products

File name	File size (bytes)	Description
prod0_METAR_SPECI.pdu	4,293	METAR, SPECI
prod1_TAF.pdu	2,977	Terminal Weather
prod2_SIGMETS.pdu	2,544	SIGMETS, AIRMETS, AWWs
prod5_PIREPS.pdu	2,005	PIREPS
region0L_prod03.pdu	2,220	Weather Depiction, CONUS
region0M_prod01.pdu	889	NEXRAD, CONUS
region0M_prod02.pdu	1,527	NEXRAD w/ Tops, CONUS

9.2 Request Products

File name	File size (bytes)	Description
region0L_prod04_fl24_t00.pdu	2,177	Winds/Temps, FL24, 00Zulu
region0L_prod04_fl30_t00.pdu	2,238	Winds/Temps, FL30, 00Zulu
region0L_prod04_fl34_t00.pdu	2,311	Winds/Temps, FL34, 00Zulu
region0L_prod05_fl05_t00.pdu	923	Turbulence, FL05, 00Zulu
region0L_prod05_fl24_t00.pdu	1,074	Turbulence, FL24, 00Zulu
region0L_prod05_fl30_t00.pdu	1,256	Turbulence, FL30, 00Zulu
region0L_prod05_fl34_t00.pdu	983	Turbulence, FL34, 00Zulu
region0L_prod06_fl24_t00.pdu	1,021	Icing, FL24, 00Zulu
region0L_prod06_fl30_t00.pdu	723	Icing, FL30, 00Zulu
region0U_prod01.pdu	401	NexRad, Region: Northwest
region0V_prod01.pdu	508	NexRad, Region: Northcentral
region0W_prod01.pdu	1,495	NexRad, Region: Northeast
region0Y_prod01.pdu	526	NexRad, Region: Southcentral
region0Z_prod01.pdu	592	NexRad, Region: Southeast

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WINCOMM

TRANSPORT EN-ROUTE SCENARIO

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VDL Mode 3 Test Flight Results

Prepared by: Russell J. Jirberg 8/26/05
Russ Jirberg - Lake Logic Systems Date

Brian Frantz 8/26/05
Brian Frantz - Verizon FNS Date

Approved by: 8/26/05
James Griner - NASA GRC Date
Scenario Lead

Michael A. Jarrell 8/26/05
Michael Jarrell - NASA GRC Date
WINCOMM Level III Project Mgr.

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1.0 Overview

NASA's Aviation Safety Program (AvSP) was created for the purpose of making a significant reduction in the incidents of weather related aviation accidents by improving weather situational awareness. The objectives of that program are being met in part through advances in weather sensor technology, and in part through advances in the communications technologies that are developed for use in the National Air Space (NAS). It is the latter element, i.e. the improvements in aviation communications technologies, that is the focus of the Weather Information Communications (WINCOMM) project.

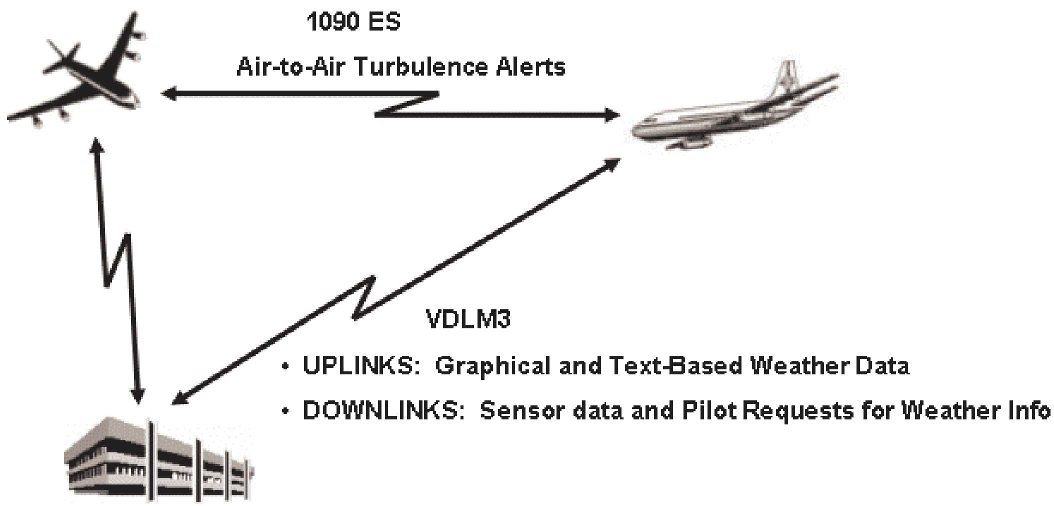


Figure 1. WINCOMM's Transport En-route Scenario

The WINCOMM Project has identified three principal aviation scenarios: (1) general aviation, (2) transport en-route, and (3) international / oceanic. Each has its own unique set of requirements. The optimal networking solution in each case is different. In the case of the Transport En-route Scenario, which is depicted in Figure 1, two near-term aviation communications technologies were selected for study. One was the 1090 MHz extended squitter (1090ES) technology; the other was the **VDL mode 3 (VDLM3)** technology. The 1090ES technology with its ability to broadcast relatively short air-to-air data messages was seen as the optimal means of disseminating real time 16-bit long turbulence alert messages between airplanes in flight. The VDLM3 technology with its ability to carry both voice and data simultaneously was seen as the optimal solution for the air-ground links. In particular, VDLM3's digital data links provide an ideal transport mechanism for the uplinking of weather data products while at the same time downlinking turbulence sensor data and pilot-initiated requests for specific weather data products.

Test flights of the 1090ES and VDLM3 data links were conducted to evaluate the performance characteristics of the two links under real-world conditions. For the testing of the 1090ES air-to-air data links, NASA equipped and flew two research aircraft. The

details and results of the 1090ES testing are documented in a companion test report (*Ref. 1*). For the testing of the VDLM3 air-ground data links, a separate series of flight tests were conducted. This report deals exclusively with the details and results of the VDLM3 testing.

VDLM3 testing was undertaken by NASA with the cooperation, technical support, and facilities of the FAA William J. Hughes Technical Center in Atlantic City, NJ, and Rockwell Collins personnel from Cedar Rapids, IA. The research aircraft were equipped and flown by NASA. Included in the airborne equipment was VDLM3 avionics produced by Rockwell Collins. The FAA supplied the ground station. NASA additionally supplied the ground-based server that managed the uplink and downlink message traffic. A series of five flights were made during the three day period of April 11 - 13, 2005. In the months leading up to the flight tests, NASA, the FAA, and Rockwell Collins separately conducted extensive laboratory testing at the subsystem level, and then jointly participated in two ground tests of the integrated system.

The VDLM3 flight tests were conducted in accordance with the requirements and objectives set forth in the Test Requirements document (*Ref. 2*) and Test Plan (*Ref. 3*) for the Transport En-route Scenario. In addition, written test procedures were developed and followed in the execution of the test flights.

2.0 VDLM3 Test System

The major subsystems that comprised the airborne and ground segments of the VDLM3 test system are depicted in Figure 2. The airborne segment was installed and flown aboard NASA's LearJet 25 research aircraft. It consisted of the VDLM3 avionics, a GPS receiver, and the WINCOMM Airborne Computer (WAC). The ground segment, which was located at the FAA's facility in Atlantic City, NJ, consisted of the FAA's ground station and the NASA WINCOMM Ground Server (WGS).

2.1 The Airborne Segment

A Rockwell Collins model VHF2100 receiver/transmitter was used as the VDLM3 radio (VDR). The weather data processing and display functions were handled using a Rockwell Collins communication management unit (CMU) together with its companion model 900 controller/display (IDC). The IDC also served as the operator interface through which requests for specific weather products were issued to the ground station. With the exception of the software modifications made to the CMU as identified in Section 4.2 of this report, the Rockwell Collins equipment was standard commercially available avionics.

The airborne computer, i.e. the WAC, handled a number of tasks. The WAC was a rack-mounted PC running MS Windows XP. It was equipped with a Condor model CEI-520A interface card which provided ARINC 429 (see *Ref. 4*) compatible serial ports for transferring data to the CMU. The computer's built in RS232 serial ports were used to

receive GPS data from the Honeywell KLN94, and to receive serial data from the monitor ports of the CMU and VDR. An LCD screen and keyboard served as the operator interface.

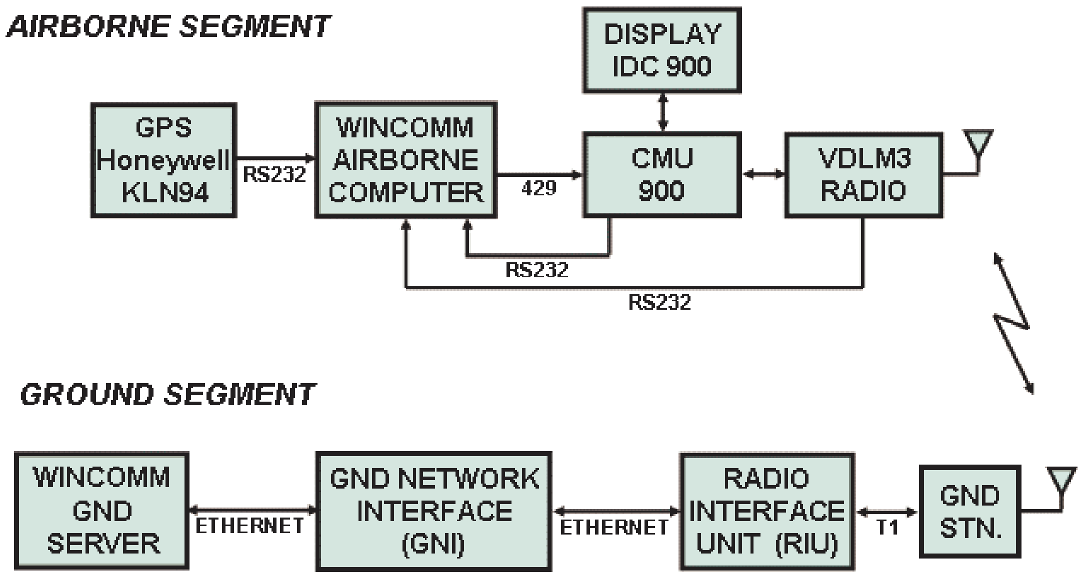


Figure 2. VDLM3 Airborne and Ground Segments

Of the "429" ports, one was configured for bi-directional communications to transfer the turbulence test messages (see Section 3.1) from the WAC to the CMU at operator selected intervals of 1 to 99 seconds. A second "429" port was configured to send the airplane's ICAO address to the CMU at fixed 250 millisecond intervals. A third "429" port was configured to send GPS data to the CMU at one second intervals.

Of the RS232 ports, one was configured to operate at the 9600 baud rate to receive GPS data from the Honeywell KLN94. A second RS232 port also operating at the 9600 baud rate was used to receive data from the monitor port of the CMU. A third RS232 port operating at 115.2 kbaud was used to receive data from the monitor port of the VDR.

Custom software was developed using LabVIEW v7.1 to manage and control many of the airborne data handling tasks. Among these tasks were: (1) the generation and logging of the turbulence test messages, (2) the management of the "429" serial data transfers from the WAC to the CMU, (3) the reading and logging of the GPS data from the KLN94, and (4) the reformatting of the GPS data for use by the CMU. The LabVIEW program also provided a means to synchronize the system clock of the WAC to the GPS. TeraTerm Pro (*Ref. 5*) was used to log the serial data received from the CMU. Custom software provided by Rockwell Collins was used to log the serial data output from the monitor port of the VDR.

The antenna for the VDR was mounted on the bottom of the fuselage at a mid-ship position. The antenna for the GPS receiver was mounted on the top of the fuselage, also at a mid-ship position.

Not shown in Figure 2 is the VDLM3 voice communications link that was used to coordinate operations between the airplane and the ground.

2.2 The Ground Segment

The FAA ground station served as the VDLM3 ground subnetwork and as the access point to the NASA WINCOMM Ground Server (WGS). The ground station consists of four primary subsystems: the Multi-Mode Digital Radios (MDRs), the Real Time Platform (RTP), the Radio Interface Unit (RIU), and the Ground Network Interface (GNI).

The MDR consists of the multi-mode digital radio receiver (MDRR) and the multi-mode digital radio transmitter (MDRT). The MDRR uses frame markers generated by the RIU to determine the slot timing for the downlink bursts. Bursts received within the intended time slots are demodulated within the MDRR and sent to the RTP. The outgoing voice/data and management bursts from the RTP are sent to the MDRT where they are modulated and transmitted using slot timing generated by the RIU.

The RTP consists of two separate elements: the Octal T1 Framer and the Voice Channel Module (VCM). The octal T1 framer sends and receives frames to and from the RIU via a high-speed serial link. Frames received from the RIU are transmitted over a fractional T1 line to the MDRT at the specified time within the frame. In the reverse direction, frames received from the MDRR via the fractional T1 line are time stamped and sent to the RIU via the high-speed serial link. The octal T1 framer also supplies system timing for use by the VCM and RIU subelements.

The RTP may contain up to four separate VCMs, providing the voice elements for up to four user groups. In the uplink direction, the analog voice input at the headset interface is digitized and then compressed by a vocoder. This compressed output is passed to the octal T1, and then sent to the RIU. In the downlink direction, compressed voice frames are passed from the RIU on the serial link, decoded in the vocoder and sent to the headset interface.

The RIU subsystem manages the Media Access Control (MAC), Link Management Entity (LME), and Data Link Service (DLS) sub-layers of the VDLM3 subnetwork. The MAC layer establishes the time division multiple access (TDMA) timing for the voice, data, and management bursts. For these tests the MAC layer was configured in accordance with the 2-voice/2-data mode of operation. The LME is responsible for context management of each air to ground connection. The DLS determines the data framing for both the unicast and broadcast modes of transmission.

The GNI serves as the data gateway to the ground station. The data to and from the RIU is transferred over an ethernet LAN. Similarly, data to and from the WGS is transferred over an ethernet LAN.

The WGS functions as the data server for the testing. It (1) periodically issued weather data products for broadcast to the airplane, (2) issued weather data products for broadcast in response to requests generated by operator key presses on the airborne IDC, (3) received the turbulence test messages transmitted from the airplane, (4) logged all incoming and outgoing message activity, and (5) provided an operator interface for monitoring and controlling ground operations. The WGS was implemented on a PC running MS Windows XP. Clock synchronization was provided through NTP services supplied via the GNI LAN connection. All traffic flowing on the LAN connection between the WGS and the GNI was logged using the Ethereal network protocol analyzer software (*Ref. 6*).

3.0 Test Messages

3.1 Turbulence Test Message (TTM)

The TTMs transmitted during these tests were all 77 bytes in length, consistent with the anticipated size of the expanded turbulence data messages. The structure of the TTMs is indicated in Table 1. Each TTM bore a timestamp that was derived from the system clock in the WAC. The clock was synchronized at the start of the each flight with the GPS time.

Byte No.	Size	Content	Description
1 – 12	12	$TURBULENCE,	Start of message
13 – 25	13	hh:mm:ss.sss,	Timestamp
26 – 31	6	nnnnn,	Sequence no.
32 – 75	44	ASCII text string	Free text message
76 – 77	2	ASCII c/r and l/f	End of message

Table 1. Turbulence Test Message (TTM) format

Included within each TTM are a message sequence number and a 44-character free-text field. Provisions were made in the WAC software to enable the airborne operator to insert short messages into the free-text field and thereby send status information to the ground personnel. A typical TTM might therefore appear as follows:

```
               1         2         3         4         5         6         7
Byte: 12345678901234567890123456789012345678901234567890123456789012345678901234567

      $TURBULENCE,09:19:51.000,00123,____________________________________________crlf
      $TURBULENCE,09:20:51.000,00124,This is a free text message.________________crlf
```

For compatibility with the CMU, the TTMs were first pre-pend with a 5-byte accountability header consisting of the 5 hex characters 57h 57h 58h 0h 0h. The resulting

82-byte data messages were then formatted in accordance with the Williamsburg version 1 file transfer protocol as specified in *Ref. 4*. This involved transforming the 82-byte data messages into a series of 32-bit words as prescribed by the ARINC 429 data transfer protocol. Each 32-bit “429” word carries no more than 5 semi-bytes (i.e. 5 nibbles) of the data message. Thus, 33 32-bit “429” words are required to contain one TTM. Two additional 32-bit words must be appended to the 33 data words to create the Link Data Unit (LDU) used in “429” data transfers. The two additional words are (1) a Start-of-Transmission (SOT) word and (2) an End-of-Transmission (EOT) word. Consequently, the transfer of the TTMs from the WAC to the CMU was accomplished using LDUs containing 35 32-bit “429” words.

Byte No.	Size	Contents	Description
1 – 5	5	001GW	Header
6 – 13	8	Ddhhmmss	Timestamp
14 – 20	7	Latitude (N1234.5)	N/S, degs, mins
21 – 28	8	Longitude (W12345.6)	E/W, degs, mins
29 – 46	18	misc.	
47 – 48	2	Sequence ID, ss	01 – 99
49 – 50	2	Region, rr	0L=continental USA
			0M=USA NEXRAD/Tops/Move
			0U=Northwest US
			0V=Northcentral US
			0W=Northeast US
			0X=Southwest US
			0Y=Southcentral US
			0Z=Southeast US
51 – 52	2	Product ID, pp	01=NEXRAD
			02=NEXRAD w/tops
			03=Weather depiction
			04=Winds and Temps
			05=Turbulence
			06=Icing
53 – 54	2	Flt Level (altitude) (as req’d)	00=FL000 30=FL300
			05=FL050 34=FL340
			10=FL100 39=FL390
			18=FL180 45=FL450
			24=FL240 53=FL530
55 – 56	2	Forecast time (as req’d.)	00=00Z 36=36HR
			06=06Z 42=42HR
			12=12Z 48=48HR
			18=18Z 60=60HR
			72=72HR

Table 2. Weather product request message format

New TTMs were automatically generated on a timed basis, generally once every 60 seconds. Additional TTMs, however, were generated on those occasions when the airborne operator chose to immediately send a text message to the ground station. The LDUs were transferred to the CMU at the 100 kbps data rate using the Williamsburg "O_1" full duplex option. The software routines used to generate the TTMs, assemble the LDUs, and provide data link flow control were implemented as part of the LabVIEW program installed on WAC.

3.2 Weather Product Request Messages

The weather product request messages are generated by the CMU in response to operator key presses on the IDC. The request message length was fixed at either 52 or 56 bytes in accordance with the message structure indicated in Table 2.

3.3 Weather Test Products (WTPs)

The weather products used in these tests to evaluate the data handling capabilities of the VDLM3 links were conventional text-based and graphical digital data types as listed in Table 3. The files were named in a manner consistent with the region and product codes

***Standard* WTP Filenames**	**Bytes**	**Description**
prod0_METAR_SPECI.pdu	4,293	METAR, SPECI
prod1_TAF.pdu	2,977	Terminal weather
prod2_SIGMETS.pdu	2,544	SIGMETS, AIRMETS, AWWs
region0L_prod03.pdu	2,220	Weather depiction, CONUS
prod5_PIREPS.pdu	2,005	PIREPS
region0M_prod02.pdu	1,527	NEXRAD w/tops, CONUS
region0M_prod01.pdu	889	NEXRAD, CONUS
***Request* WTP Filenames**	**Bytes**	**Description**
region0L_prod04_fl24_t00.pdu	2,177	Winds/Temps, FL24, 00Z
region0L_prod04_fl30_t00.pdu	2,238	Winds/Temps, FL30, 00Z
region0L_prod04_fl34_t00.pdu	2,311	Winds/Temps, FL34, 00Z
region0L_prod05_fl05_t00.pdu	923	Turbulence, FL05, 00Z
region0L_prod05_fl24_t00.pdu	1,074	Turbulence, FL24, 00Z
region0L_prod05_fl30_t00.pdu	1,256	Turbulence, FL30, 00Z
region0L_prod05_fl34_t00.pdu	983	Turbulence, FL34, 00Z
region0L_prod06_fl24_t00.pdu	1,021	Icing, FL24, 00Z
region0L_prod06_fl30_t00.pdu	723	Icing, FL30, 00Z
region0U_prod01.pdu	401	NEXRAD, Region: Northwest
region0V_prod01.pdu	508	NEXRAD, Region: Northcentral
region0W_prod01.pdu	1,495	NEXRAD, Region: Northeast
region0Y_prod01.pdu	526	NEXRAD, Region: Southcentral
region0Z_prod01.pdu	592	NEXRAD, Region: Southeast

Table 3. Weather Test Products (WTPs)

listed in Table 2. The graphical products are PNG image files reformatted as ADPUs in accordance with RTCA DO-267 (*Ref. 7*). The textual WTP sizes were chosen based on the average product sizes of complete national compressed weather information as observed in the Flight Information Services Data Link System (and also in *Ref. 8*). The textual WTPs are uncompressed ASCII files that contain portions of actual national weather products. The sizes of the WTPs were scaled down by a factor of seven (7) from the size of the corresponding national weather product file size in order to make the WTP file sizes consistent with those of regional products. The graphical WTPs are PNG-format files that contain actual weather data samples from a weather-intensive day in the U.S. The data in the graphical WTPs does not include any geo-political borders, as this information is stored and rendered on the IDC. See Appendix B for screen shots of the WTPs.

For the purposes of these tests, the WTPs were divided into two sets: a ***standard*** set and a ***request*** set. The ***standard*** WTPs were broadcast by the ground station on a rotating schedule basis. The transmissions were separated by a 10-second inter-message wait period. After cycling through all of the products in the ***standard*** set, the process was repeated starting again with the first product in the set. The ***request*** WTPs, on the other hand, were broadcast only once in response to a request for that particular WTP. The requests were queued by the server upon receipt and subsequently posted to the GNI for broadcast.

4.0 Data Transfer Protocols

4.1 VDLM3

The VDLM3 communications took place in full compliance with the protocols and procedures established by RTCA MASPS document (*Ref. 9*) and RTCA MOPS document (*Ref. 10*). The VDLM3 system was configured for operation with two voice channels and two data channel, i.e. the so called 2V2D option. Only one of the two data channels was used. Voice traffic was occasionally carried on one of the voice channels during the test flights.

4.2 TCP/UDP/IP

All test messages were transmitted as IP datagrams. TCP/IP v4 was selected as the data transfer protocol for the downlinking of (1) the TTM messages and (2) the WTP request messages. UDP/IP was selected as the data transfer protocol for the uplink broadcasts of the WTPs. The decision to use TCP/IP (versus ATN) was based on the fact that TCP provided an entirely adequate reliable data transfer mechanism for the downlinking of the turbulence and WTP ***request*** test messages from the airplane. In addition, the UDP provided a convenient file transfer mechanism for the uplink broadcasts of the WTPs from the ground station. The VDLM3 standard allows for the use of IPv4 by setting the IPI field in the DLS frame to 0xCC as per ISO 9577. It also allows for the use of ATN.

However, an ATN implementation would have required the addition of a full ATN protocol stack to both the WGS and the CMU. This was seen as an unnecessarily more complex and costly alternative.

IP-based messaging was implemented in the CMU with the addition of the Treck v2.2 TCP/IP protocol stack to the CMU's embedded software. IP-based messaging in the ground station was implemented using the TCP/IP protocol stack built into the MS Windows XP operating system. For the purposes of these tests, no changes were made to the Windows XP default TCP timer values in the WGS. The maximum transmission unit (MTU) size, however, was changed to 922 bytes for compatibility with the amount of data transferred by VDLM3 in one 15-burst data frame (see Figure 3). In the CMU, the key TCP/IP stack parameters were set as indicated in Table 4.

IP Parameters:	**Value**
Support IP fragmentation	1=Yes
IP Time to live (TTL)	64
IP Type of service (TOS)	0
IP fragment re-assembly TTL	90 seconds
TCP Parameters:	
Max keep alive count	8
Keep alive idle time	7200 sec.
Probe timeout interval min.	500 millisec.
Probe timeout interval max.	60 sec.
Max. retransmit count	12
Max. retransmit time	75 sec.
Retransmission timeout default	3 sec.
Retransmission timeout min.	2 sec.
Retransmission timeout max.	12 sec.
Delay ACK time	200 millisec.

Table 4. Airborne (CMU) TCP/IP parameters

Message prioritization was implemented using the Type-of-Service (TOS) bits contained within the IP headers to convey the VDLM3 priority levels. For the purposes of these tests, the ***standard*** WTPs were given a high priority by the ground server by having their TOS bits set to the value 2. The ***request*** WTPs were given a lower priority by the ground server by having their TOS bits set to the value 1. The TOS bit settings for the TCP flags were unaltered from their default values. Thus, the TCP *ACK*, *SYN*, and *FIN* packets were sent with priority 2, while the TCP *RST* packets were sent with priority 0.

4.3 VDLM3/IP Effective Data Throughput Rate

VDLM3, operating in the 2V2D mode, provides a base data transfer rate of 192 symbols (72 bytes) per 120 milliseconds in each of its two data channels. Excluding the 10 forward error correction bytes carried in each data burst, the data rate at the data link layer

is effectively 62 bytes per 120 milliseconds per data channel. Overhead bytes are added at the DLS layer and at the IP layer as indicated in Figure 3.

At the transport layer, an 8-byte UDP header is pre-pended to the ADPU data block in creating a UDP/IP datagram. The UDP datagrams are segmented for transport into a number of IP fragments, the size of which is limited by the MTU size. With the MTU set to 922 bytes, each fragment will contain a maximum of 896 bytes. Hence, an ADPU containing N bytes will be segmented into n fragments such that:

$$n = n_{full} + n_{partial}$$

where

$$n_{full} = \text{Floor}\left[(N + 8) \text{ modulo } 896\right]$$

and

$$n_{partial} = 1 \text{ if Remainder}\left[(N + 8) \text{ modulo } 896\right] > 0$$

or

$$n_{partial} = 0 \text{ if Remainder}\left[(N + 8) \text{ modulo } 896\right] = 0$$

At the link layer, the IP fragments are framed for transport into data link service (DLS) frames, each of which adds 8 additional header bytes to each IP fragment. Thus at the VDLM3 transport layer, each full DLS frame is transported as a series of 15 VDLM3 62-byte data bursts plus a proportionately smaller number of bursts for the final IP fragment.

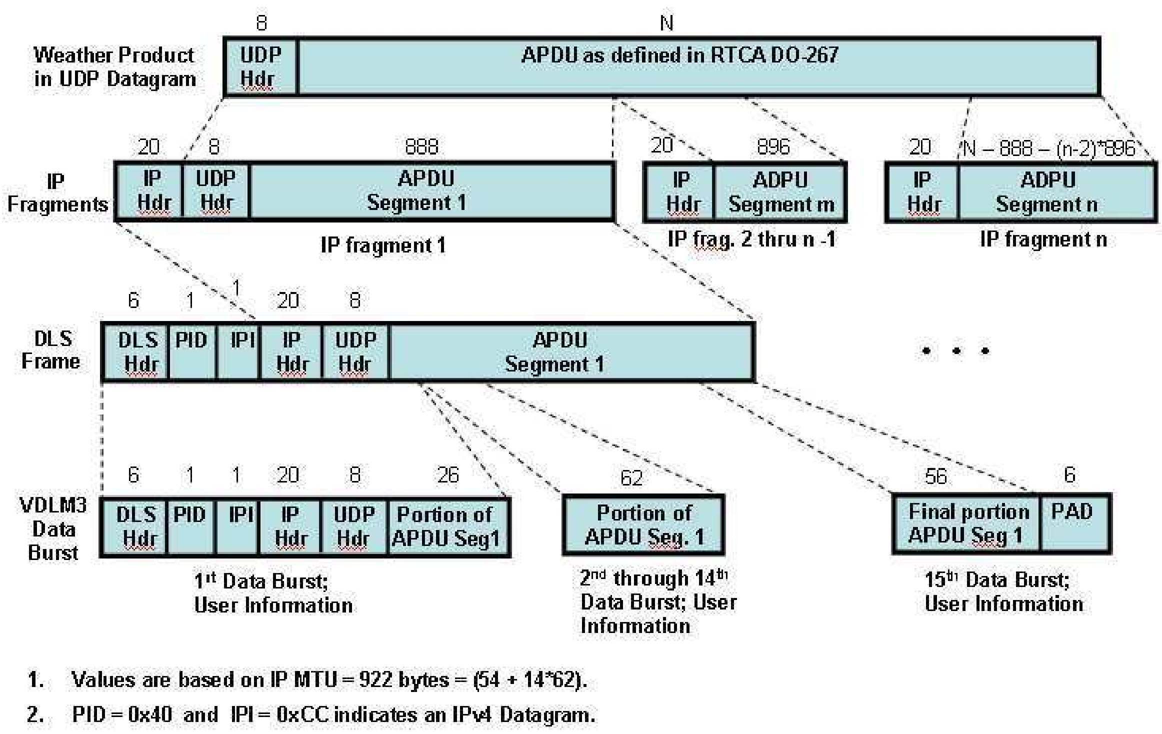


Figure 3. Segmentation of VDLM3 / IP data messages

Based on the segmentation indicated above, the anticipated delivery time for an ADPU varies linearly as a function of its file size as shown in Figure 4. Also shown are the number of IP fragments (full and partial) required to deliver the ADPU file. The indicated effective transfer rate is nominally 490 bytes per second (3.92 kbps). When compared to the 72-byte per 120-millisecond VDLM3 base data rate, i.e. 600 bytes per second, the channel efficiency is approximately 82%. In actual practice, the presence of TCP and VDLM3 protocol traffic interleaved with the data packets serve to reduce this effective rate somewhat. Thus, the 490 byte per second rate per VDLM3 data channel represents the maximum effective transfer rate for IP datagrams.

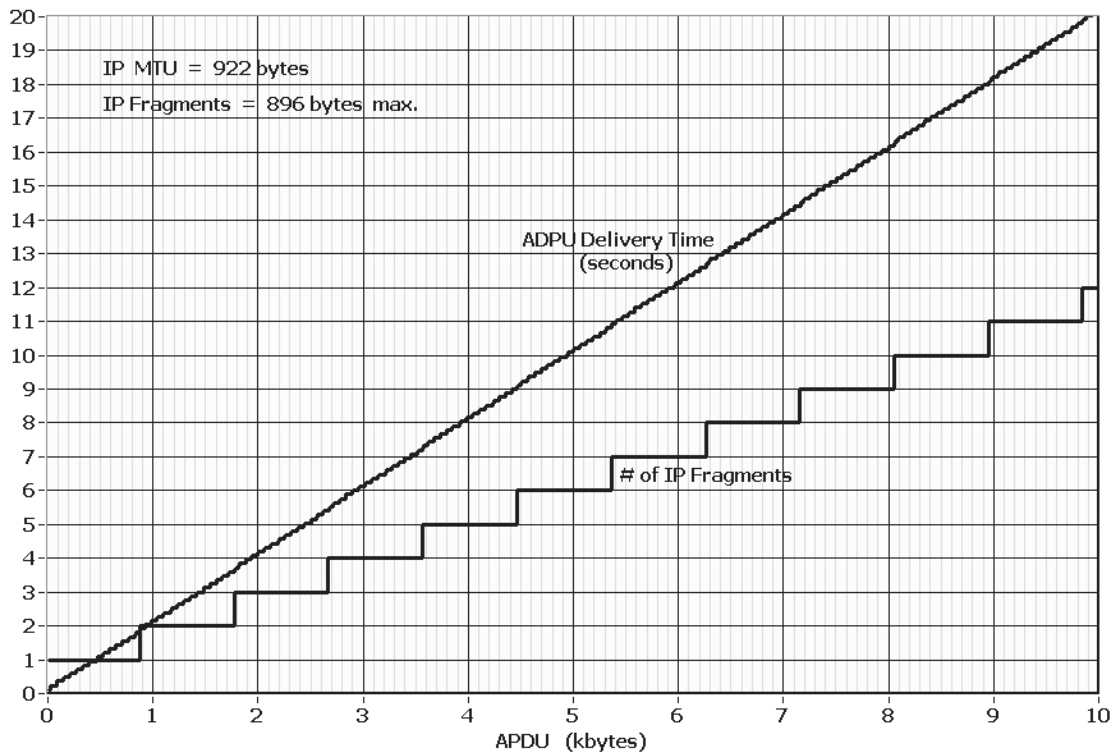


Figure 4. Maximum anticipated VDLM3 transfer of IP datagrams

5.0 Flight Profiles

A series of five test flights of the VDLM3 system were made during the period of April 11-13, 2005. All were flown out of the Atlantic City, NJ airport (ACY) within range of the FAA's VDML3 ground station located at the FAA Technical Center. Shown in Figure 5 is the flight pattern for Flight #2. The flight patterns for Flights #3 through #5 (not shown) were similar to that for Flight #2.

The flights were all made under straight and level conditions, and under generally clear-sky conditions. Each flight consisted of four legs: 2 out-bound legs and 2 in-bound legs. The turnarounds on the out-bound legs were made approximately 2 minutes after

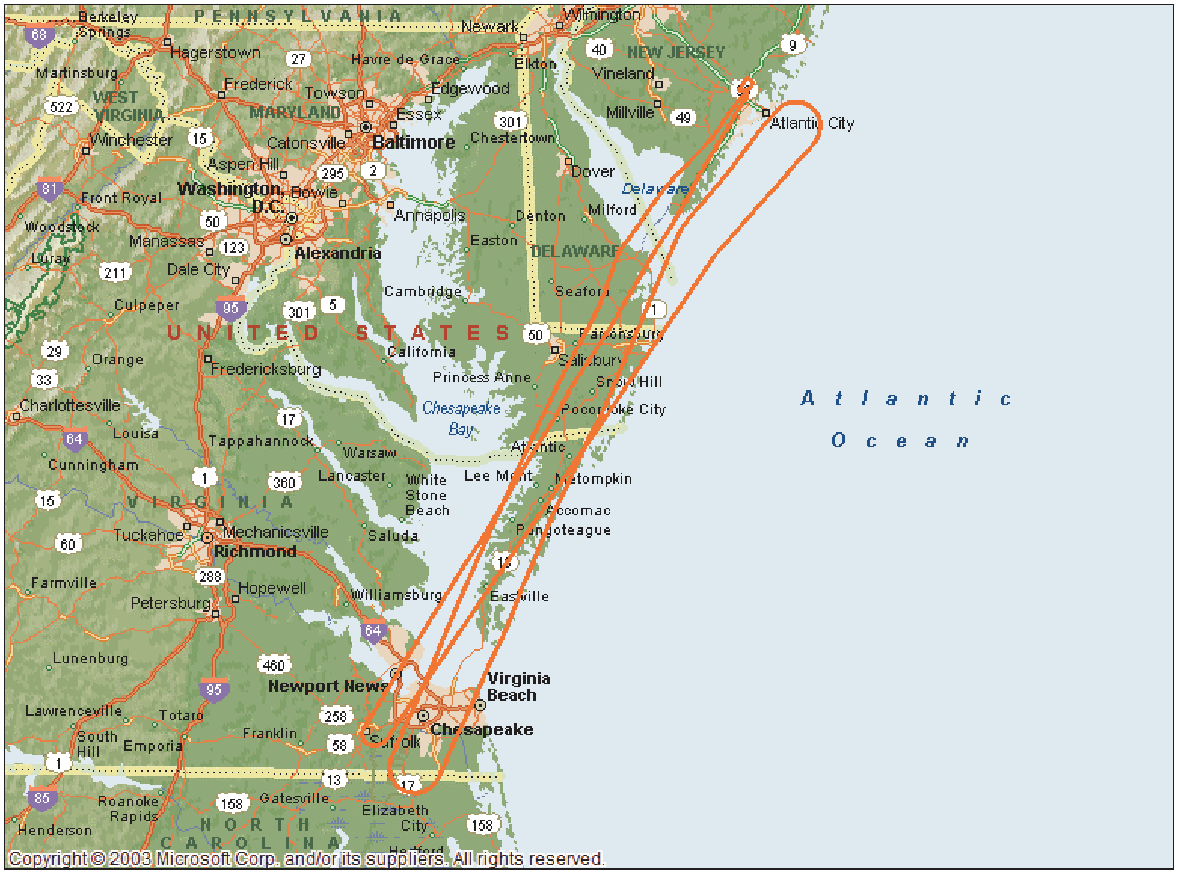


Figure 5. Flight #2 flight path.

Flight/Leg	Altitude (feet)	STD WTPs Spacing	STD WTPs Datafile	REQ WTPs Interval	REQ WTPs Datafile	TTM Interval
2 / 1	35,000	10 sec.	Full set	-	none	60 sec.
2 / 2	35,000	10 sec.	Full set	5 min.	Full set	60 sec.
2 / 3	35,000	10 sec.	Full set	5 min.	Full set	60 sec.
2 / 4	35,000	10 sec.	Full set	5 min.	Full set	60 sec.
3 / 1	35,000	10 sec.	Full set	5 min.	Full set	60 sec.
3 / 2	35,000	10 sec.	Full set	2 min.	Full set	30 sec.
3 / 3	35,000	10 sec.	Full set	2 min.	Full set	30 sec.
3 / 4	35,000	10 sec.	Full set	2 min.	Full set	30 sec.
4 / 1	24,000	10 sec.	Full set	2 min.	Full set	30 sec.
4 / 2	24,000	10 sec.	Full set	2 min.	Full set	30 sec.
4 / 3	24,000	10 sec.	Full set	2 min.	Full set	30 sec.
4 / 4	24,000	10 sec.	Full set	2 min.	Full set	30 sec.
5 / 1	24,000	10 sec.	Full set	1 min.	Full set	15 sec.
5 / 2	24,000	10 sec.	Full set	1 min.	Full set	15 sec.
5 / 3	24,000	10 sec.	Full set	1 min.	Full set	15 sec.
5 / 4	24,000	10 sec.	Full set	1 min.	Full set	15 sec.

Table 5. Flight parameters

observing a complete loss-of-signal. Throughout each flight, the ***standard*** WTPs and TTMs were transmitted on a regularly scheduled basis. The ***request*** WTPs were broadcast only in response to a request from the airplane.

Flight #1 served as a checkout flight. The Flight #1 data is not included in this analysis. The data logged during Flights #2 through #5 constitute the test data upon which the test results in this report are based. The test flights differ mainly in (1) the altitudes flown, (2) the complement of weather products transmitted and requested, (3) the intervals at which the operator-initiated WTP requests were issued, and (4) the interval at which the TTMs were issued. The flight parameters for each flight are summarized in Table 5.

Additionally, during the second, third and fourth legs of Flight #5, rapid-fire bursts of requests were made for the 14 ***request*** WTPs.

Shown in Figure 6 is a plot of the SQP values obtained during Flight #2. The plot is typical of the observed variation in SQP values for all of the flights. The SQP variations in the 0 – 12 minute and 138 – 140 minute timeframes shown in Figure 6 are associated with the takeoff and landing maneuvers. The SQP = 0 values that occurred in the 44-minute and 104-minute timeframes coincide with the out-of-range turnarounds of the flight.

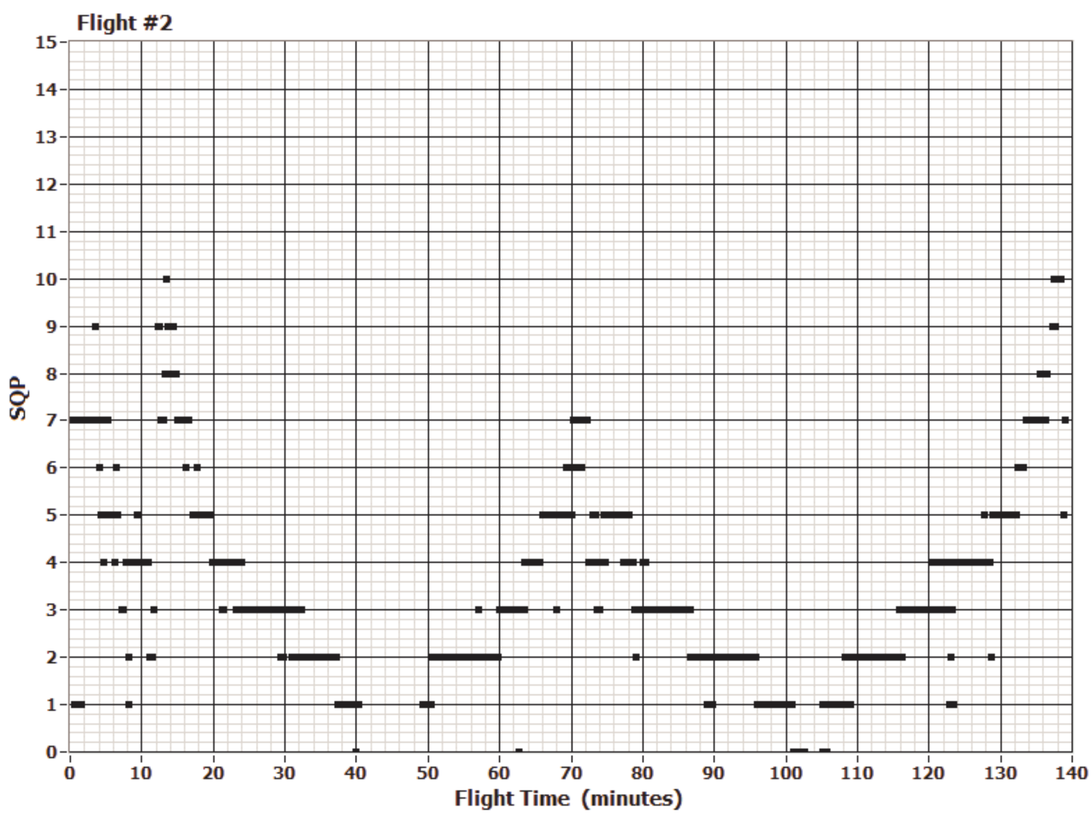


Figure 6. Observed SQP variations – Flight #2 (typical)

6.0 Test Results

6.1 UDP/IP Broadcast Message Results

As indicated in Table 5, the ***standard*** WTPs listed in Table 3 were repeatedly broadcast in a cyclical manner. The number of broadcasts made per flights ranged from 407 to 455. The total number of WTPs broadcast was 1,705. The success rate was determined by matching the IP IDs of the WTPs in the WGS Ethereal logs to those contained in the VDR logs and looking for lost WTPs. The dependence of the success rate on SQP was essentially the same for all four data flights. Figure 7 was constructed by combining the results from the four flights and plotting it as a function of the receive SQP threshold.

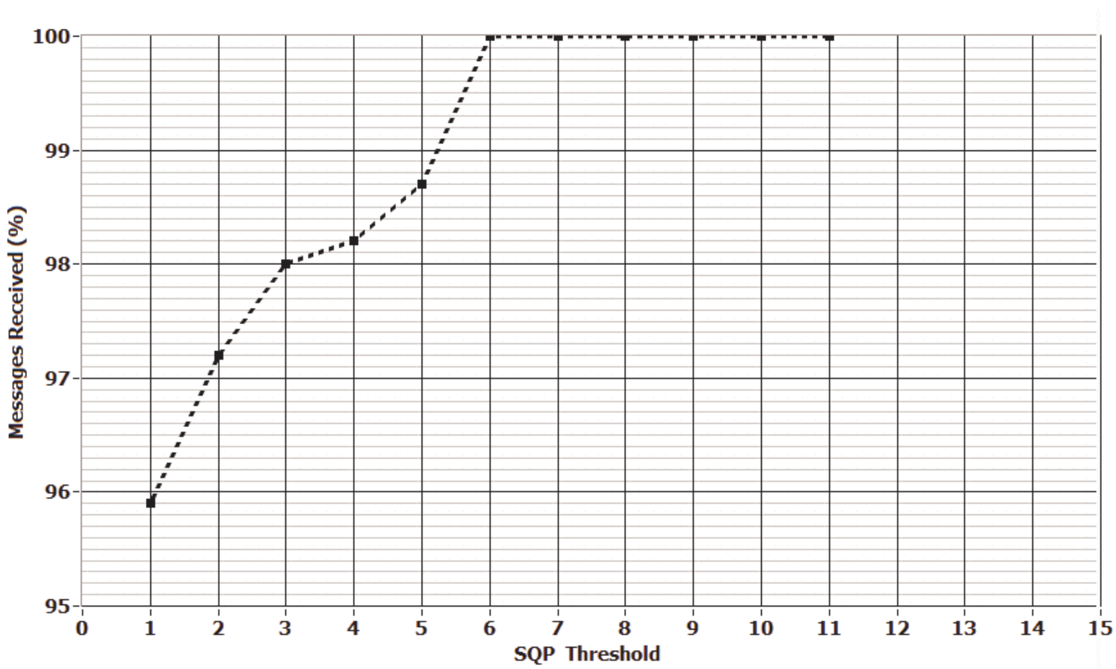


Figure 7. UDP uplink broadcast delivery success rates

The data acquired during those segments of the flight for which the observed SQP value was zero were excluded from the plot. An SQP value of zero indicated that the aircraft was effectively out-of-range.

Shown in Figure 8 are the message delivery times for the seven ***standard*** WTPs for Flights #2 through #5. The data in these plots was derived from the packet flows captured in the VDR logs and the WGS Ethereal logs. Clock corrections were applied to the data as explained in Appendix A. The delivery time for a WTP was computed as the difference between the timestamp for receipt of the final IP fragment of the WTP from the VDR log and the timestamp for the start of the message from the WGS Ethereal log. The observed delivery times are consistent with the theoretical maximum transfer rate of 490 bytes per second (see Section 4.3). The scatter in the data is believed to be due to the variations in the amount of interleaved protocol traffic that existed on the channel during the broadcast.

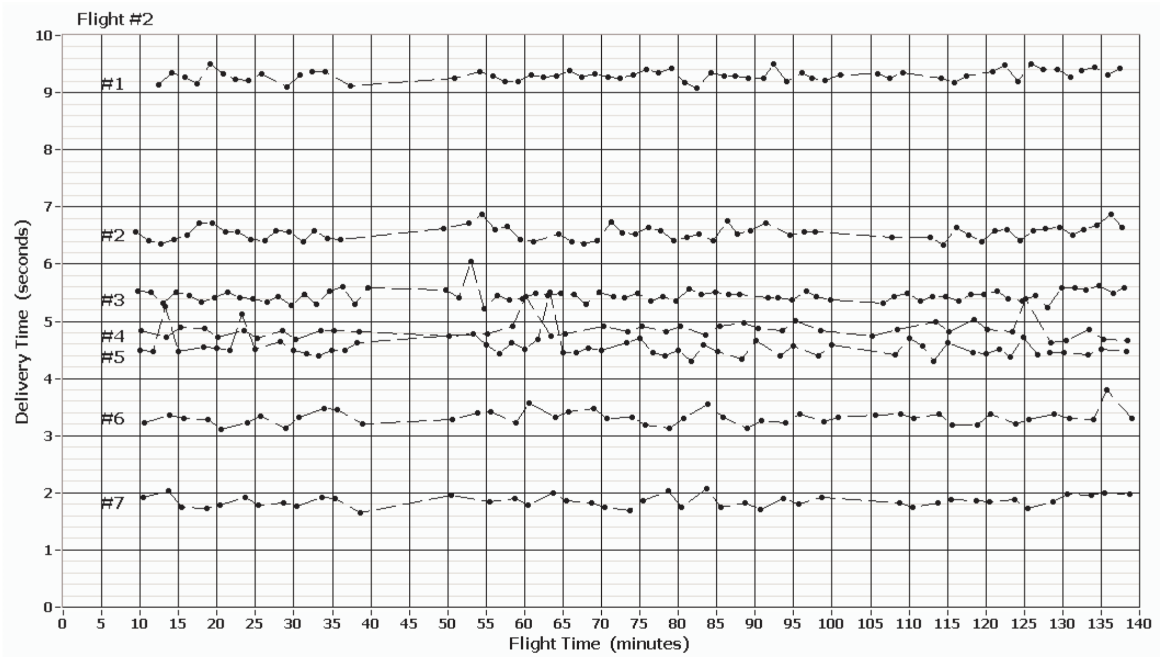


Figure 8a. ***Standard*** WTP delivery times – Flight #2

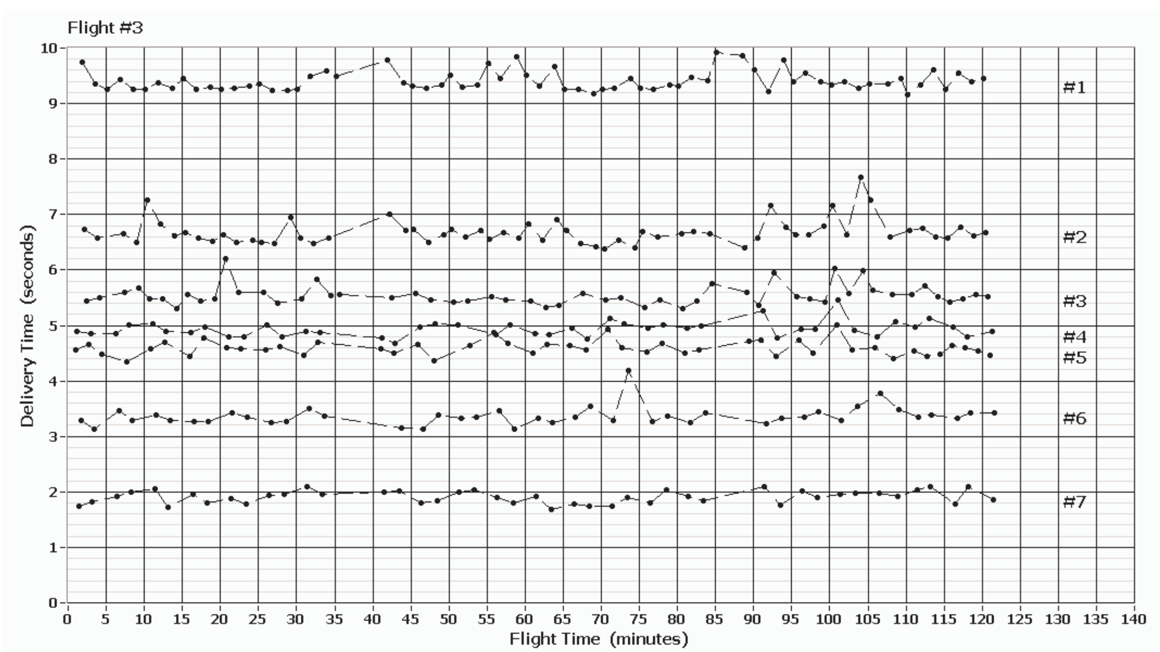


Figure 8b. ***Standard*** WTP delivery times – Flight #3

WTP	#1	#2	#3	#4	#5	#6	#7
Bytes	4,293	2,977	2,544	2,220	2,005	1,527	889
Desc.	METAR	Term. Wx	SIGMETS	Wx CONUS	PIREPS	NEXRAD	NEXRAD

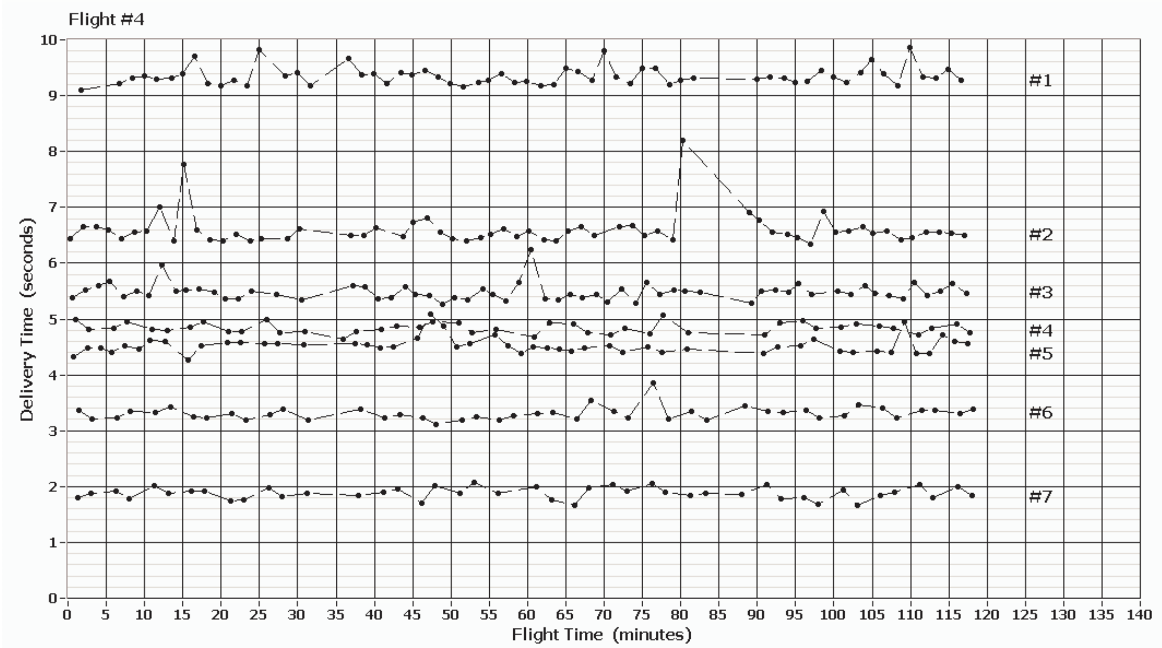


Figure 8c. ***Standard*** WTP delivery times – Flight #4

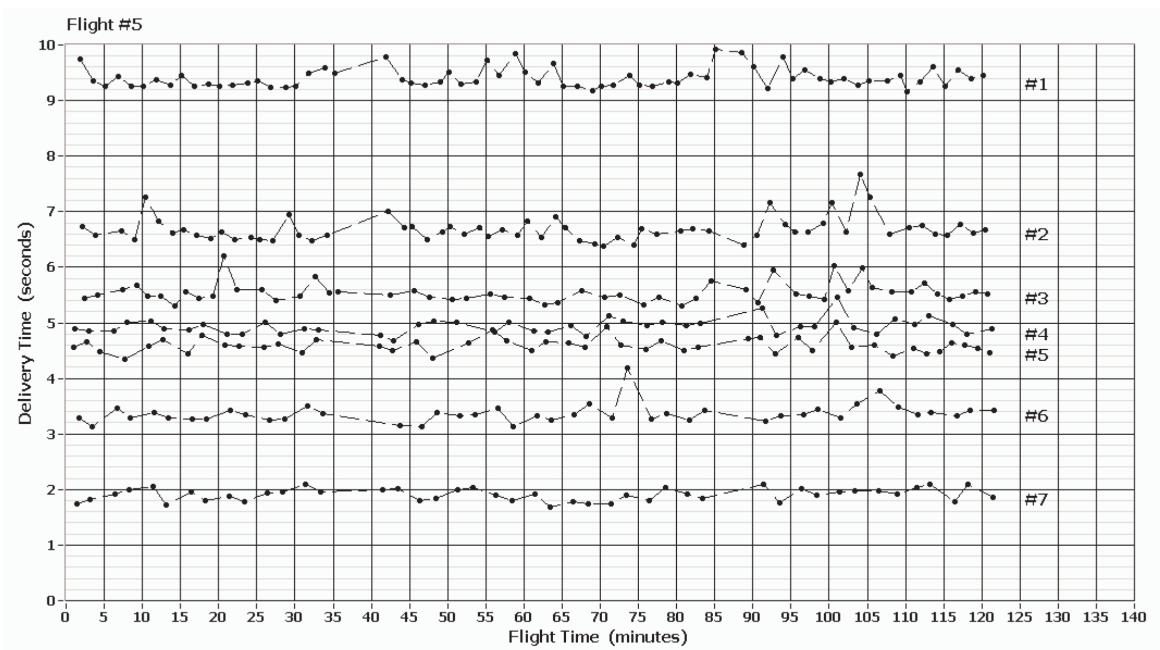


Figure 8d. ***Standard*** WTP delivery times – Flight #5

WTP	#1	#2	#3	#4	#5	#6	#7
Bytes	4,293	2,977	2,544	2,220	2,005	1,527	889
Desc.	METAR	Term. Wx	SIGMETS	Wx CONUS	PIREPS	NEXRAD	NEXRAD

6.2 Turbulence Test Message Results

Shown in Figure 9 are the observed delivery times for the TTMs for the four data flights. The data for these plots was obtained from the WGS Ethereal logs. The delivery times were computed as the difference between the timestamp for the receipt of the TTM and the timestamp written to the time field of the message by the WAC when it was created. Clock corrections were applied to the data as explained in Appendix A.

Considerable variability is observed in the delivery times for all of the flights. Since the TTMs were sent periodically throughout the course of each flight, the conditions under which the TTMs were transmitted covered a broad range of SQP values: from SQP values of 11 down to 0. The variations in SQP value do not correlate well with the observed scatter in the delivery time data. Instead, it is more likely that the scatter is due solely to packet retransmissions.

Summarized in Table 7 are the TTM results in terms of messages sent versus messages received as obtained from the WAC and WGS logs. Significantly, no TTMs were lost, as would be expected of a reliable transport protocol. However, through analysis of the packet flows in the VDR and WGS Ethereal logs, it was determined that there were numerous retransmissions at both the TCP layer and the DLS layer.

	Flt. #2	Flt. #3	Flt. #4	Flt. #5
TTMs Sent	136	122	217	444
TTMs Rec'd.	136	122	217	444
TTMs Lost	0	0	0	0
Retransmissions:				
at the TCP layer	5	6	20	34
at the DLS layer	55	32	49	93

Table 6. TCP messaging of the turbulence messages.

The reason(s) for the inordinately large number of retransmissions that occurred, particularly those that occurred at the DLS layer, is not obvious. In some instances there is evidence in the packet flows that a conflict existed between the TCP and VDLM3 timers. However, further study and/or experimentation will be required to isolate the reason(s) for the retransmissions and to optimize the protocol timers. In addition, there are other potential causes for message latency variations which warrant investigation. These include the WAC-to-CMU Williamsburg data transfers and the CMU-to-VDR message processing delays.

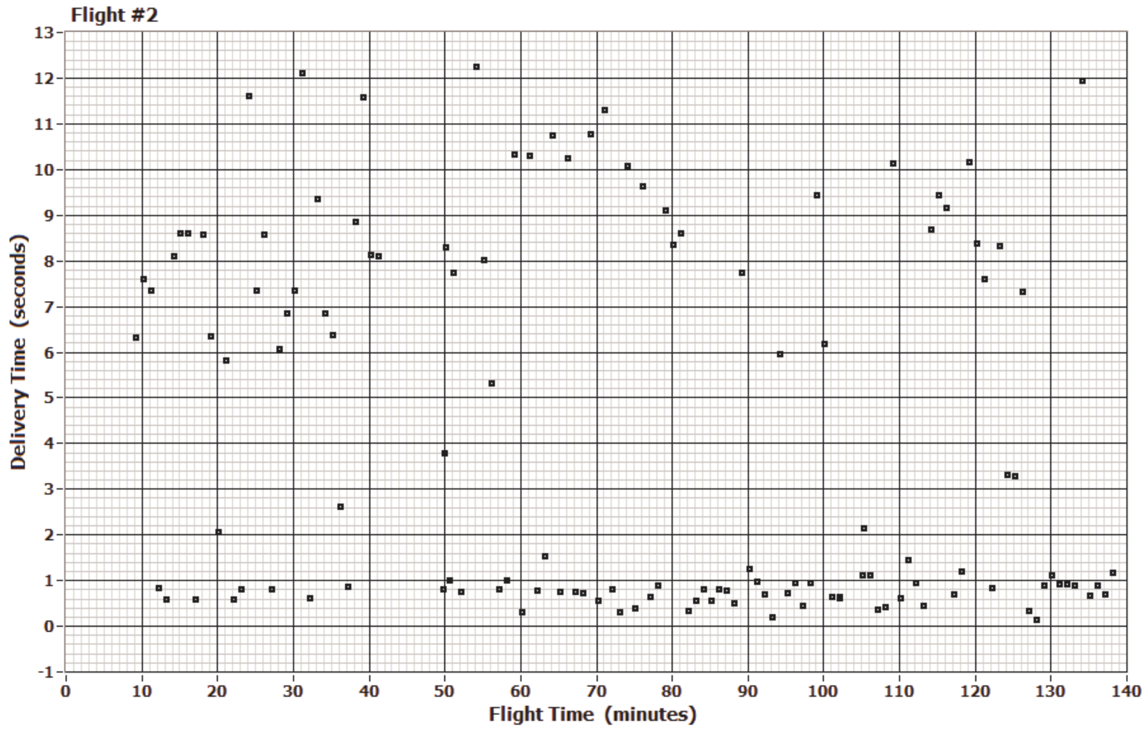


Figure 9a. TTM delivery times – Flight #2

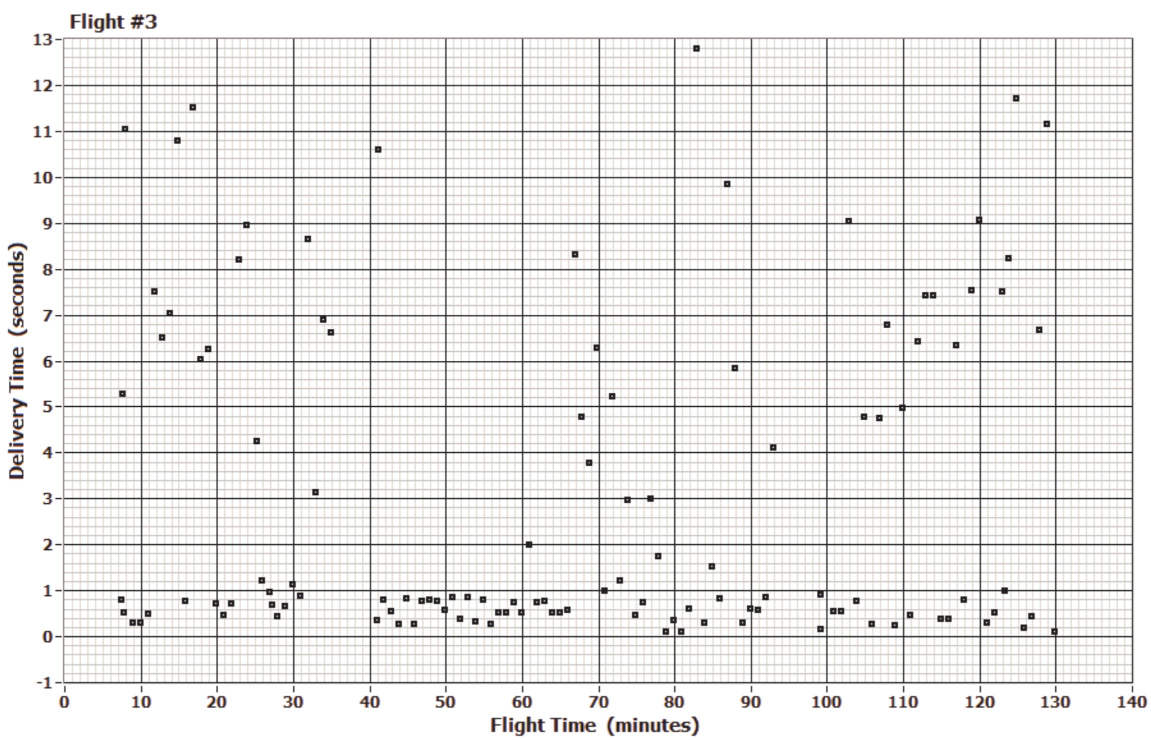


Figure 9b. TTM delivery times – Flight #3

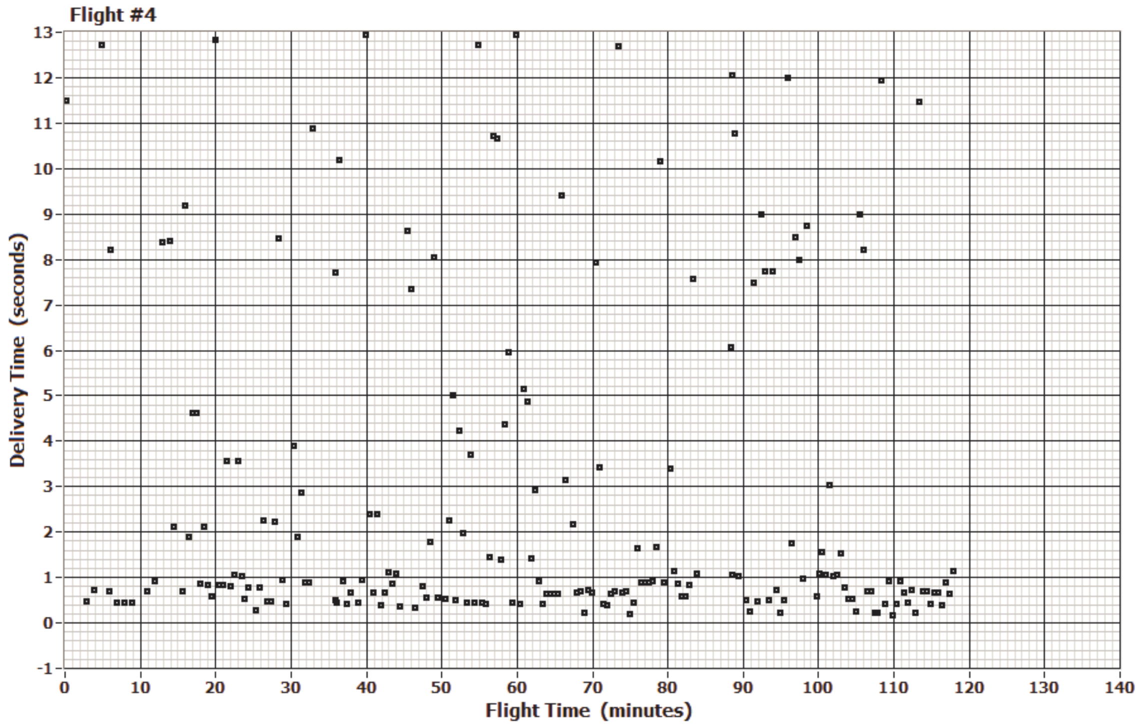


Figure 9c. TTM delivery times – Flight #4

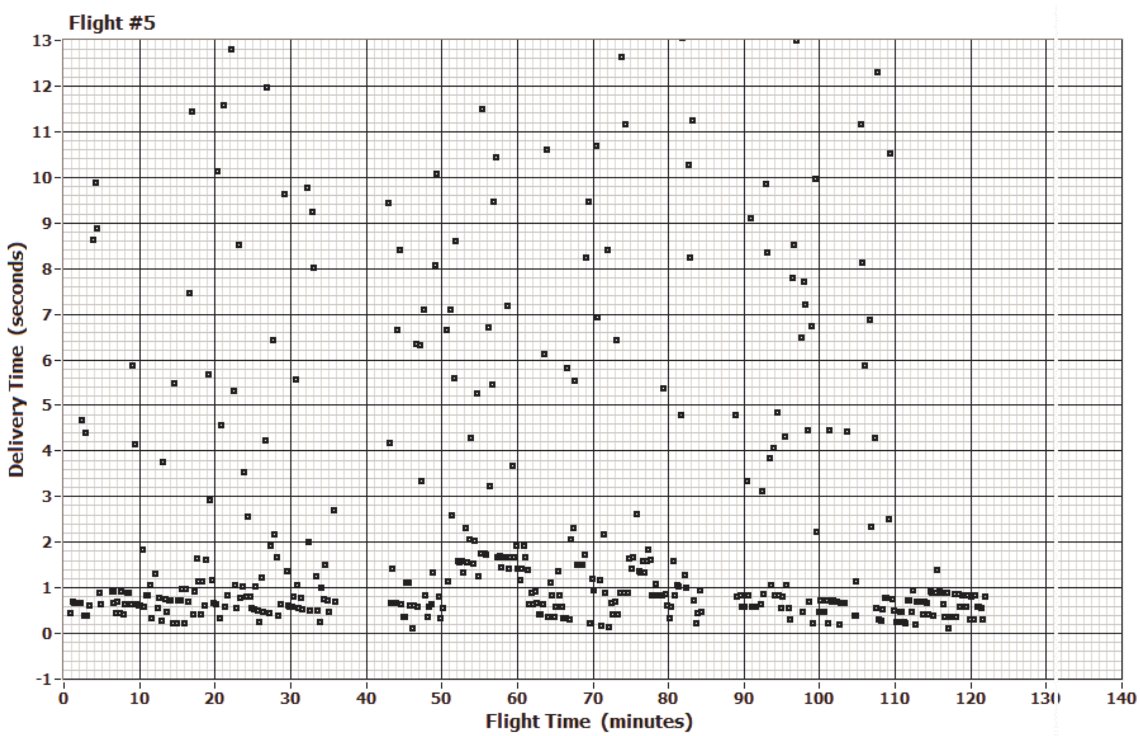


Figure 9d. TTM delivery times – Flight #5

6.3 WTP *Request* Message Results

Shown in Figure 10 are the observed delivery times for the WTP ***request*** messages. The data in these plots was derived from the timestamps captured in the VDR log and in the WGS Ethereal log. Clock corrections were applied to the data as explained in Appendix A.

As in the case of the TTMs, considerable variability exists in the observed delivery times of the ***request*** messages. Much of the data is clustered in the 240 millisecond regime, which corresponds to the transmit time of a 52 or 56 byte message (i.e. two 120-millisecond VDLM3 data bursts). However, the data in part is also clustered in the 3 - 4 second regime, which is suggestive of the 3-second TCP retransmission time of the Treck TCP protocol stack. Since the ***request*** messages were sent sporadically throughout the course of the four data flights, the transmissions occurred under wide ranging conditions: under SQP values ranging from 0 to 11. Thus, as in the case of the TTMs, the scatter in the data does not correlate well with the SQP value. Instead, it is likely that the scatter is due solely to packet retransmissions. Indeed, such is the case as was revealed from an analysis of the packet flows obtained from the VDR and WGS Ethereal logs.

Summarized in Table 7 is the number of ***request*** messages sent versus the number received. This data was obtained from the VDR log and from the WGS Request log. The fact that not one of the ***request*** messages was lost is to be expected given that the messages were sent using a reliable transport protocol. However, an analysis of the packet flows indicates that a substantial number of retransmissions had taken place, especially at the DLS layer. The reason for these retransmissions is not immediately obvious. The packet flows, though, suggest that they may be due to inappropriately set TCP timers relative to the VDLM3 timers. Further study and experimentation will be required to optimize the system parameters.

	Flt. #2	Flt. #3	Flt. #4	Flt. #5
REQs Sent	16	43	43	102
REQs Rec'd.	16	43	43	102
REQs Lost	0	0	0	0
Retransmissions:				
at TCP layer	5	11	6	6
at DLS layer	4	20	8	30

Table 7. TCP messaging of the WTP ***request*** messages.

It should be noted that there was a difference at the *application* protocol layer of the ground server for TCP connections of the ***request*** messages and the TTMs. In the case of the ***request*** messages, the ground server was programmed to drop the current connection after 2.5 minutes of inactivity and establish a new connection upon receipt of the next ***request*** message. In the case of the TTMs, the ground server was programmed to maintain the connection indefinitely. No evidence, however, was found to suggest that this difference contributed materially to the scatter in the delivery times of the ***request*** messages.

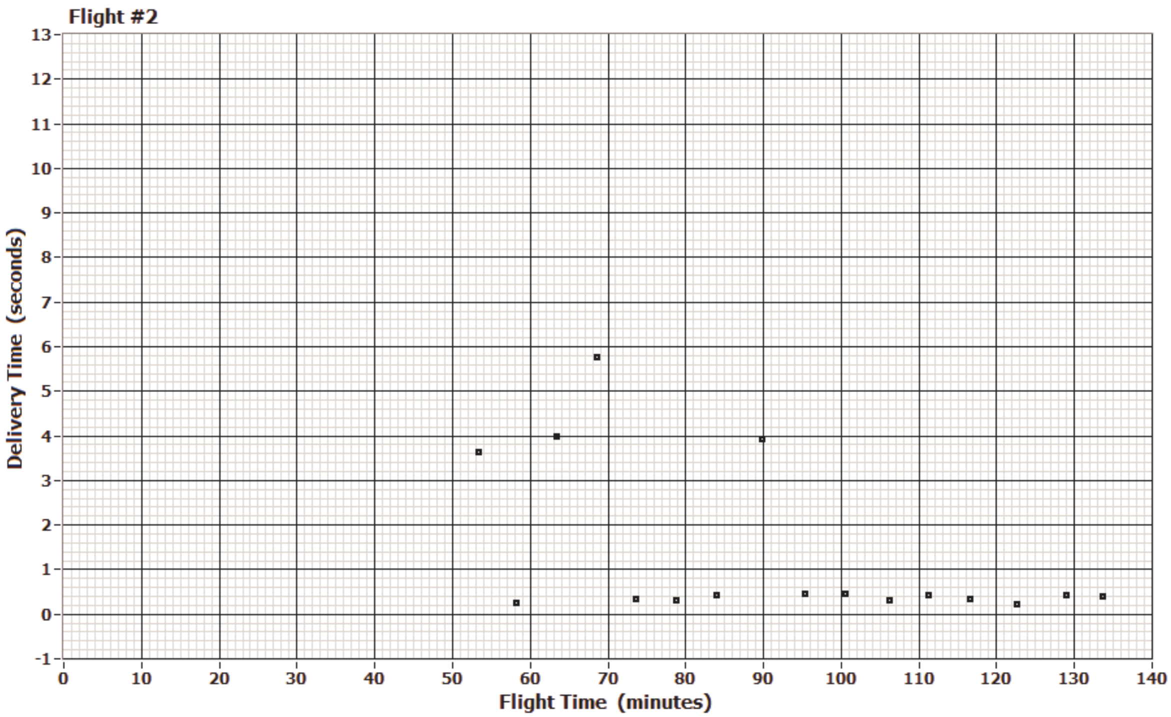


Figure 10a. WTP ***Request*** message delivery times – Flight #2

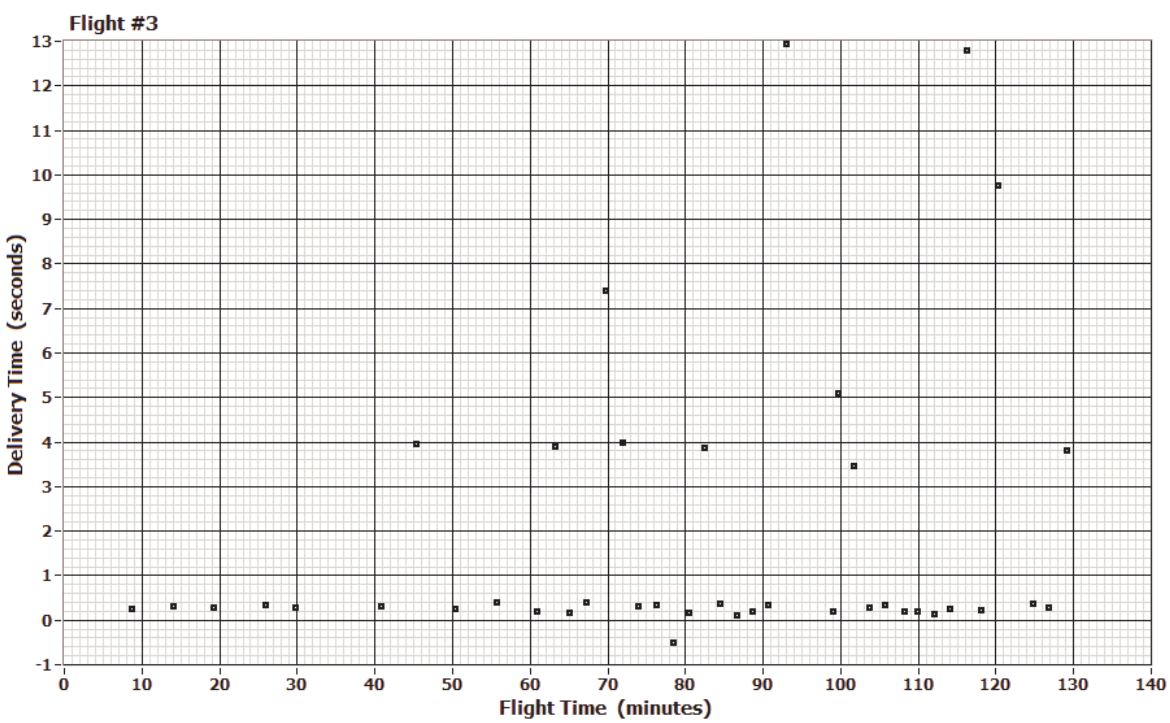


Figure 10b. WTP ***Request*** message delivery times – Flight #3

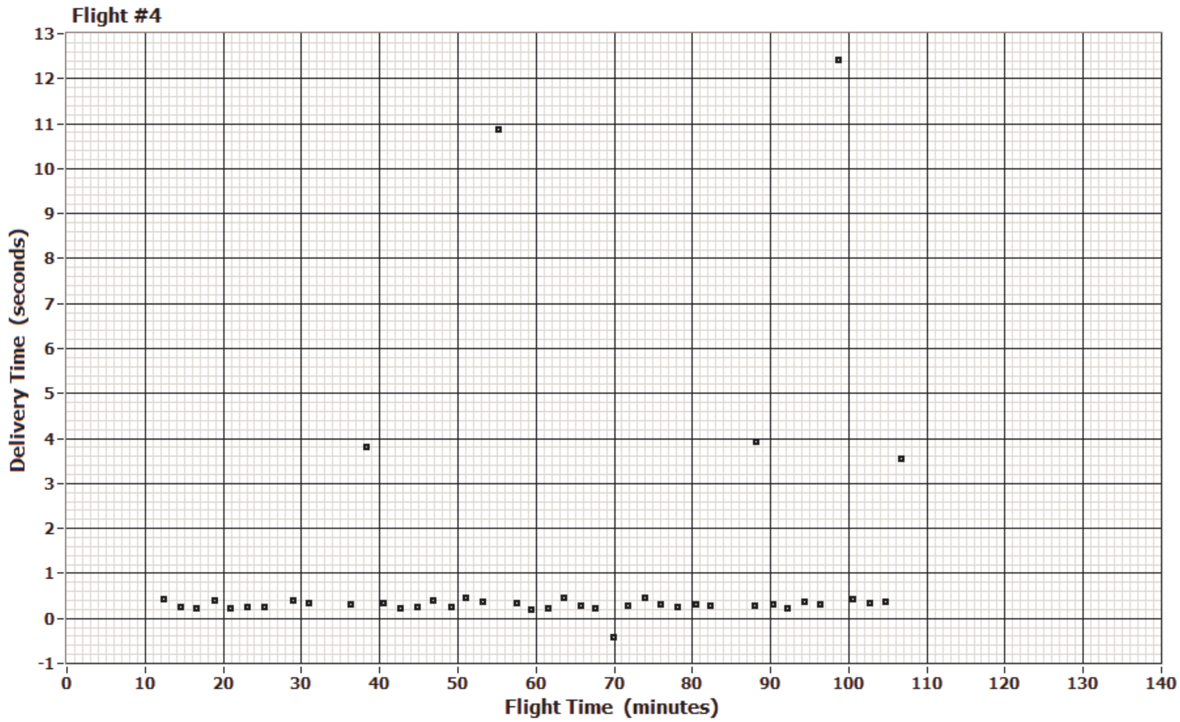


Figure 10c. WTP ***Request*** message delivery times – Flight #4

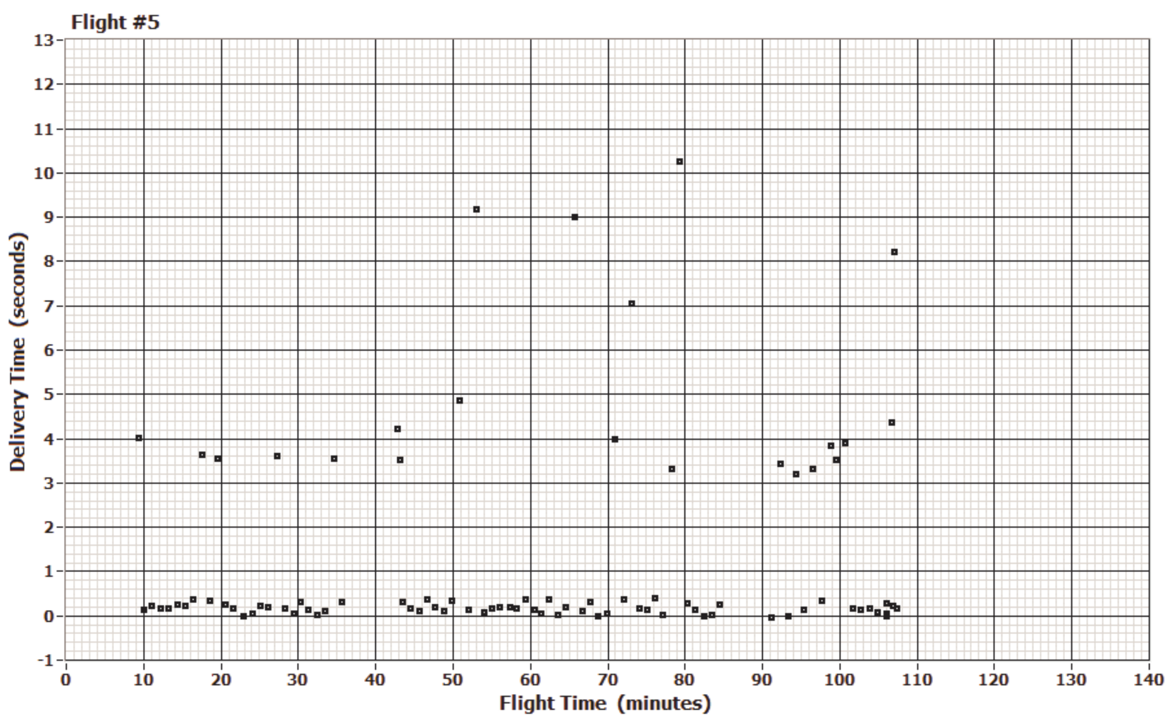


Figure 10d. WTP ***Request*** message delivery times – Flight #5

7.0 Concluding Remarks

These tests establish VDLM3 as a viable medium for the delivery of weather data to airplanes in flight. Furthermore the tests demonstrate that VDLM3 can be combined with a reliable transport protocol such as TCP/IP for point-to-point air-to-ground messaging. And importantly, the tests demonstrate that VDLM3 can be combined with a best-efforts transport protocol such as UDP/IP for ground-to-air broadcasts of aviation weather data products.

Packet retransmissions resulting from inappropriately set protocol timers were found to introduce large variations in the delivery times of the data messages, thus degrading the average delivery times of the data messages. Further study and/or experimentation will be required to optimize the protocol timers and thereby achieve optimally responsive applications.

APPENDIX A - Clock Corrections

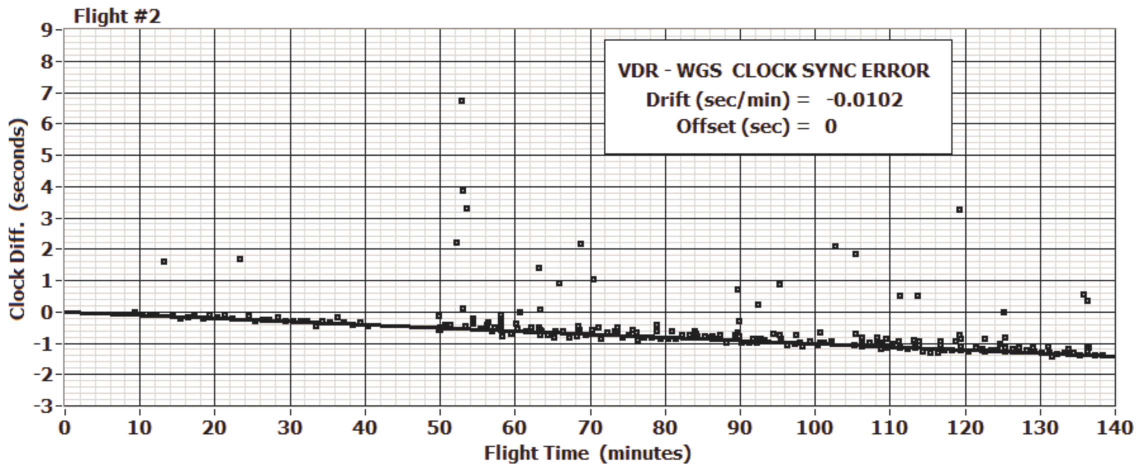
The time stamps for the various data sets recorded as part of this study were derived from four different clocks: (1) the WAC system clock, (2) the CMU internal clock, (3) the VDR internal clock, and (4) the WAC clock. At the start of each flight the WAC clock was synchronized to the airborne GPS time. The WAC in turn passed its clock timing to the CMU (via an ARINC 429 serial port). The VDR subsequently synchronized its clock to the CMU clock. At the ground station the WGS was synchronized to an NTP server via the ethernet link to the GNI. In reviewing the various data sets, it became apparent that the synchronization process did not achieve a perfectly synchronized set of clocks. Not only were there significant offsets found among these four clocks, but also a significant drift.

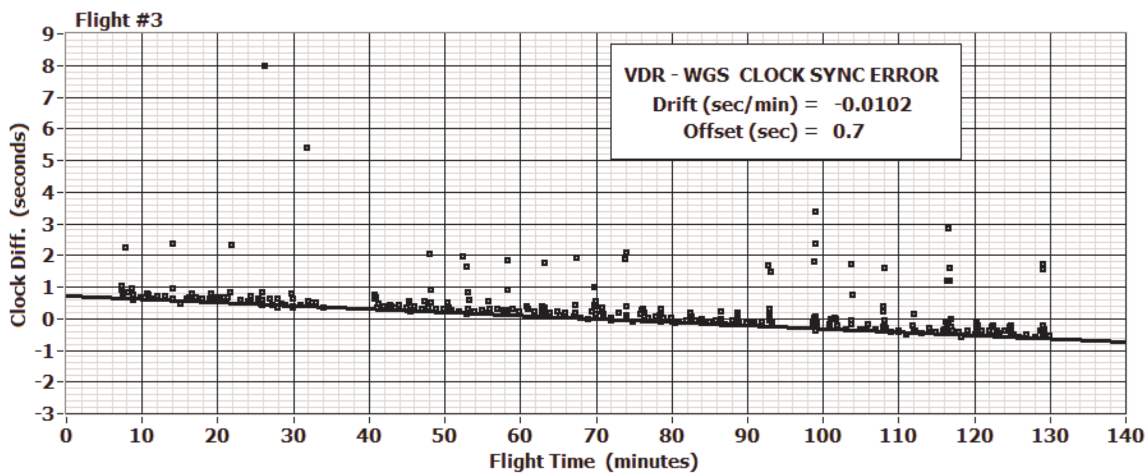
The difference between the VDR and WGS clocks was obtained by noting the differences between the timestamps in the packet flows for the TCP *ACKs* when they were received at the VDR versus when they were transmitted from the WGS. The *ACKs* were selected because of their small fixed (52 byte) packet size, thus assuring that the two timestamps should be 120-millisecond apart, i.e. the time of one VDLM3 data burst. In order to compare the timestamps, the VDR logs were first converted to the Libpcap format. This made it possible to compare the VDR packet flows with those captured by Ethereal at the WGS. Plots of the timestamp differences, minus the 120 millisecond delivery time, are shown on the following pages. The plots indicate that the VDR clock drifted linearly with respect to the WGS clock.

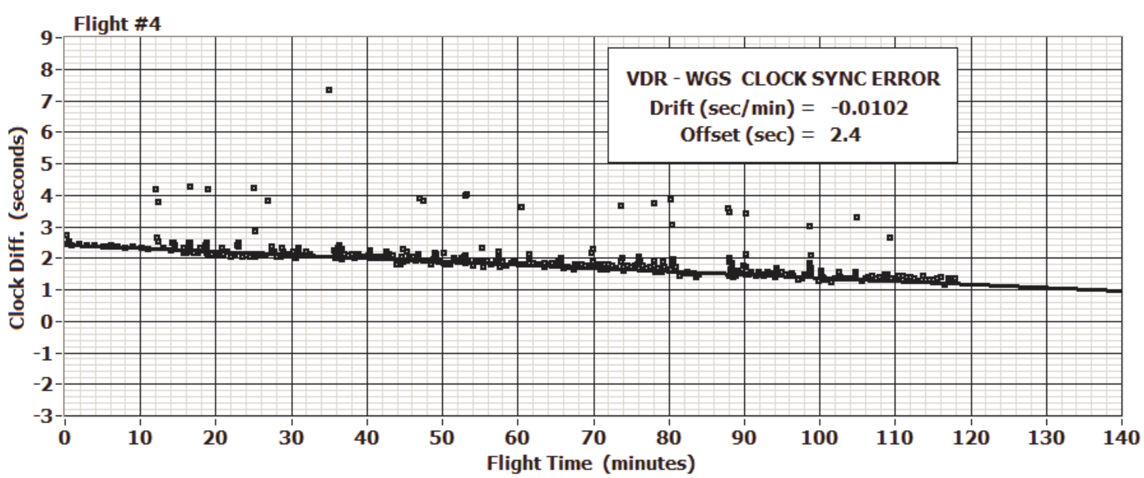
In a similar manner, the difference between the VDR and WAC clocks was obtained by noting the differences between the timestamps in the packet flows for the arrival of the TTMs at the VDR versus the timestamps embedded in the TTM itself by the WAC. Plots of these timestamp differences are also shown on the following pages. The plots indicate that the VDR and WAC clocks were offset by a fixed amount with no apparent drift.

The data plotted in Figures 8 and 10 were corrected by applying the linear clock correction for the VDR-WGS synchronization error. The data plotted in Figure 9 were corrected by applying both the VDR-WGS linear clock correction and the constant offset VDR-WAC clock correction.

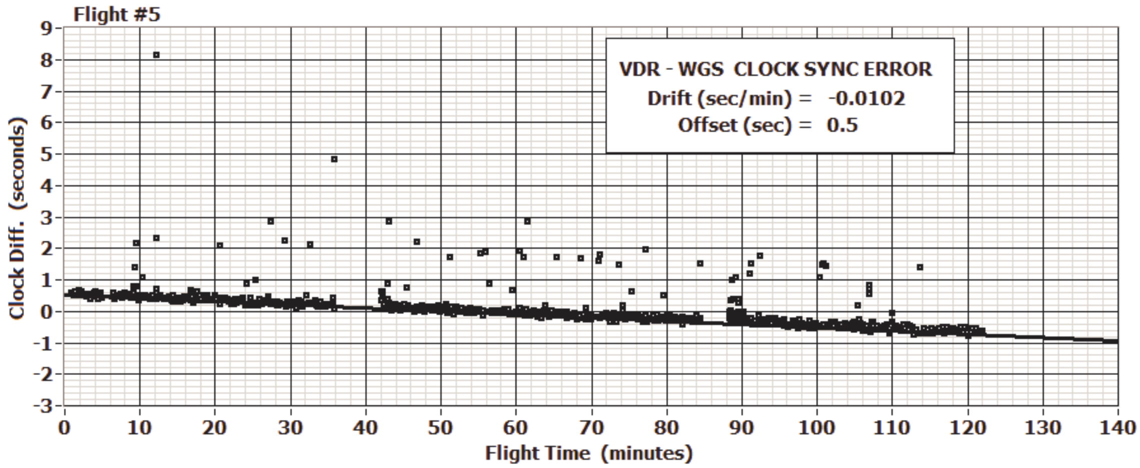
VDR-WGS Clock Corrections



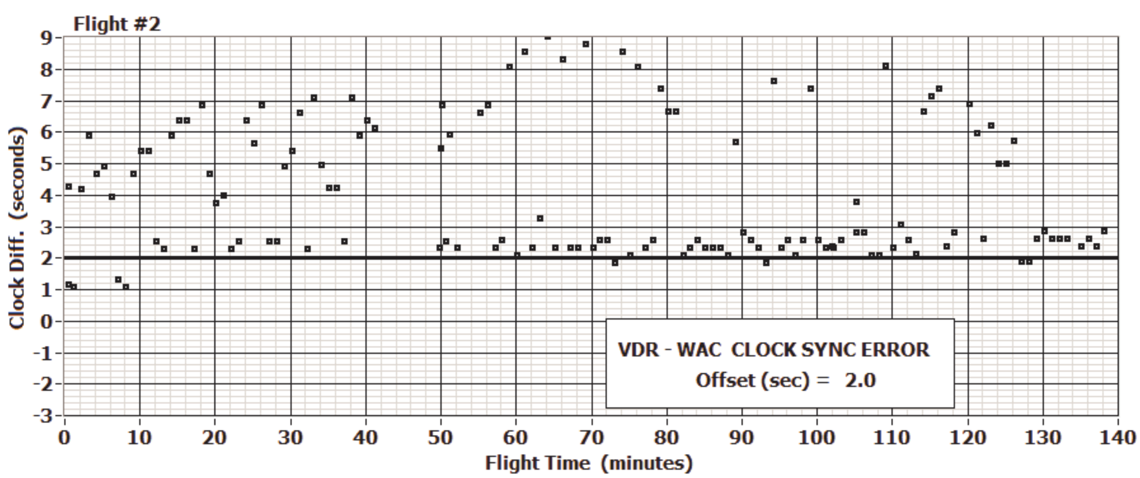




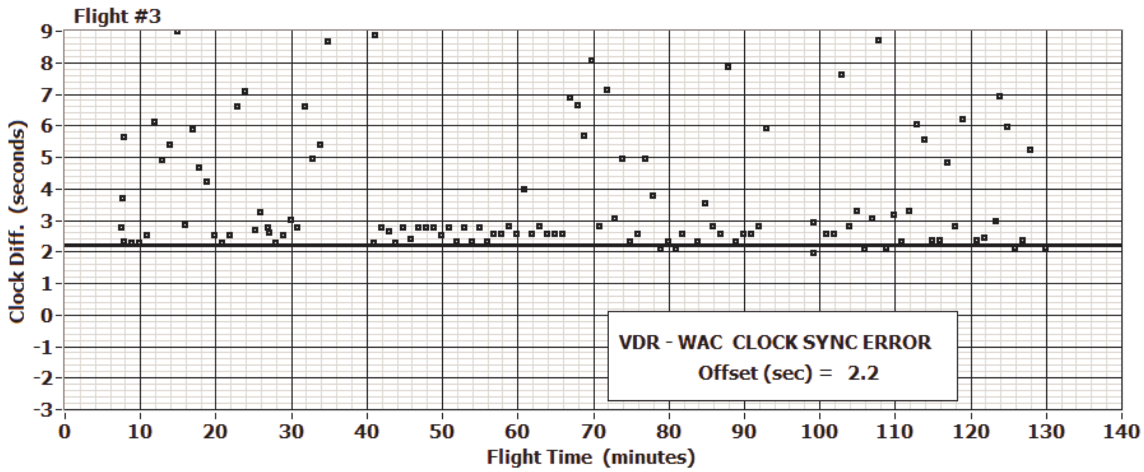
VDR-WGS Clock Corrections (continued)

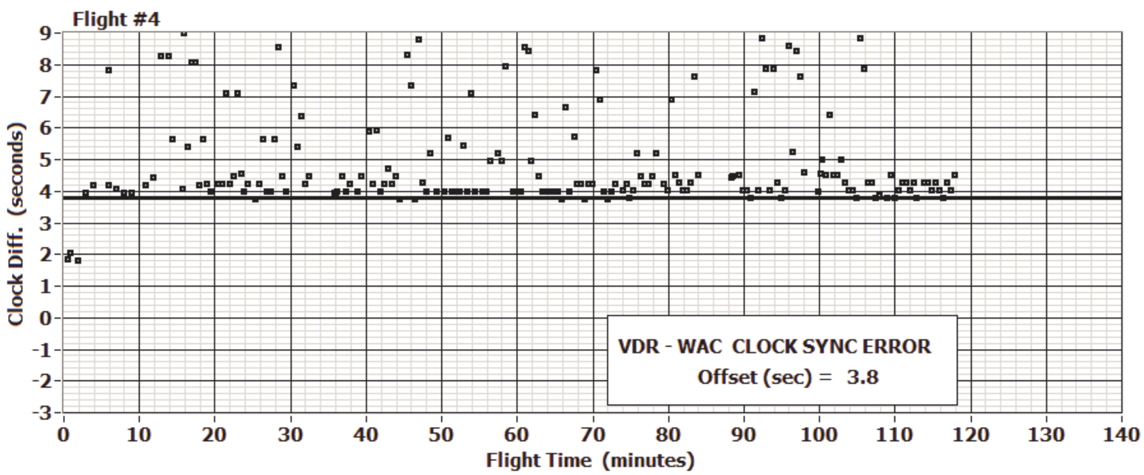


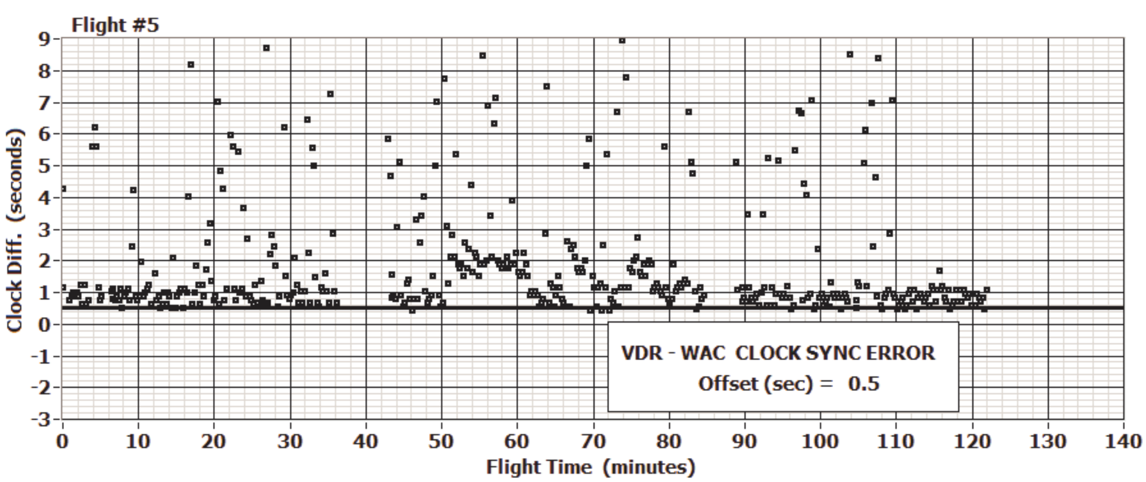
VDR-WAC Clock Corrections



VDR-WAC Clock Corrections (continued)





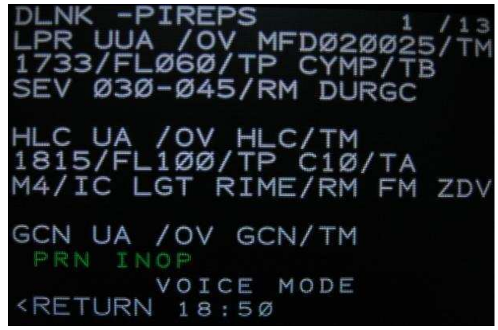


APPENDIX B - Weather Test Products

On the following pages are screen photographs of the ***standard*** and ***request*** WTPs as they appeared on the IDC. The graphical images were in color. The data files do not contain the geo-political boundaries; the boundaries were added by the IDC.

Standard WTPs

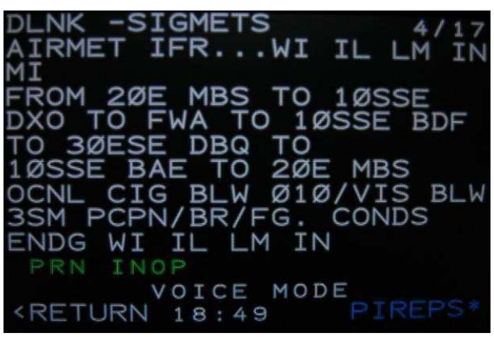
METAR, SPECI (4,293 bytes)



PIREPS (2,005 bytes)

Terminal Weather (2,977 bytes)

NEXRAD, w/tops (1,527 bytes)



SIGMETS, AIRMETS (2,544 bytes)

NEXRAD, CONUS (889 bytes)

Weather Depiction (2,220 bytes)

Request WTPs

Winds/Temps, FL24, 00Z (2,177 bytes)

Turbulence, FL24, 00Z (1,074 bytes)

Winds/Temps, FL30, 00Z (2,238 bytes)

Turbulence, FL30, 00Z (1,256 bytes)

Winds/Temps, FL34, 00Z (2,311 bytes)

Turbulence, FL34, 00Z (983 bytes)

Turbulence, FL05, 00Z (923 bytes)

Icing, FL24, 00Z (1,021 bytes)

***Request* WTPs (continued)**

Icing, FL 30, 00Z   (723 bytes)

NEXRAD, Northeast   (1,495 bytes)

NEXRAD, Northwest (401 bytes)

NEXRAD, Southcentral (526 bytes)

NEXRAD, Northcentral (508 bytes)

NEXRAD, Southeast   (592 bytes)

REFERENCES

1. Transport En-route Scenario 1090 ES Test Results, WINCOMM Project, NASA Glenn Research Center, Cleveland, OH, (to be published)

2. Transport En-route Scenario Test Requirements, WINCOMM Project, NASA Glenn Research Center, Cleveland, OH, (to be published)

3. Transport En-route Scenario Test Plan, WINCOMM Project, NASA Glenn Research Center, Cleveland, OH, (to be published)

4. ARINC Specification 429P3-18, Mark 33 Digital Information Transfer System (DITS), Part 3, File Data Transfer Techniques, October 12, 2001.

5. TeraTerm Pro Web, Enhanced Telnet / SSH2 Client, version 3.1.3, Ayera Technologies, Inc. (http://www.ayera.com).

6. Ethereal Network Protocol Analyzer, version 0.10.12. (http://www.ethereal.com).

7. Minimum Aviation System Performance Standards (MASPS) for Flight Information Services - Broadcast (FIS-B) Data Link, RTCA/ DO-267, March 27, 2001.

8. WINCOMM ConOps/Requirements and Architecture for Air Transport Scenario. Thomas Tanger, version 1.0. (to be published)

9. Signal-in-Space Minimum Aviation System Performance Standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques, RTCA/ DO-224A change 1 and 2, October 12, 2001.

10. Minimum Operational Performance Standards (MOPS) for Aircraft VDL Mode 3 Transceiver Operating in the Frequency Range 117.975-137.000 MHZ, RTCA/ DO-271B, October 12, 2001.

National Aeronautics and
Space Administration

DATE: 09/16/2005

AVIATION SAFETY PROGRAM (ASP)

Weather Accident Prevention

Weather Information Communications (WINCOMM)

Commercial Transport Scenario

1090 Extended Squitter Test Report

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Weather Information Communications

(WINCOMM)

Commercial Transport Scenario

1090 Extended Squitter Test Report

Prepared by:

9-16-05

Brian A. Kachmar – Analex Corporation

Date

Approved by:

9/16/2005

James Griner
Scenario Lead

Date

Michael A Jarrell

9-16-2005

Michael Jarrell – NASA GRC
WINCOMM Level III Project Manager

Date

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1.0 SCOPE

One of the goals of the Weather Information Communications (WINCOMM) project is to develop advanced communications and information technologies to enable reliable and timely dissemination of weather information to aircraft.

No single data link was considered optimal for the distribution of weather data for air to air, ground to air broadcast, and air to ground two-way communication. Therefore, it was necessary for WINCOMM to implement a hybrid approach. VDLM3 was selected for own ship turbulence events to ground users and 1090ES was chosen to transmit own ship turbulence data to other aircraft. The choice for 1090ES was facilitated by the announcement by the FAA that 1090ES shall be the data link for commercial operators for Automatic Dependent Surveillance Broadcast (ADS-B).

To research this approach, WINCOMM initiated a Flight Testing program to evaluate these communications links in an actual flight environment. 1090 Extended Squitter (1090ES) is the data link of focus in this paper.

2.0 INTRODUCTION

1090 Extended Squitter, which is based on Mode S technology, is an extended use of the standard 1090MHz transponder frequency. The standard 1090ES use is the transmission of position information off of the aircraft utilizing Automatic Dependent Surveillance Broadcast (ADS-B) transmissions.

WINCOMM used an ADS-B transmission to transmit Turbulence Test Alert (TTA) messages to other aircraft. Since a normal ADS-B contains positional information as well as the time and altitude, there is no need for this data to be duplicated in the turbulence message. As a result, all 16 bits of the TTA can be used for weather related data. These additional 16 bits will be inserted as a payload to a standard ADS-B message, in compliance with DO-260A [RTCA2003].

Ultimately, an algorithm that is fed input from various sensors onboard the aircraft would determine the normalized turbulence information. The normalized turbulence information output from the algorithm would be used to generate a TTA message. However, during these flight tests, emulated turbulence information was exchanged due to the absence of such an algorithm.

3.0 GOALS and OBJECTIVES

The goal of the 1090ES test is to successfully demonstrate the transmission of weather data over the 1090 communication link. More specifically, the weather data represents a turbulence test alert message.

ICAO Annex 10, Volume II, Amendment 77 defines the BDS (Comm-B Data Selector) code 4, 5 as the Meteorological Hazard Report [WIL2004]. Its purpose is to supply reports on the severity of meteorological hazards. BDS 4, 5 are the registers where the turbulence test alert message is to be stored. However, the contents of these registers have been re-defined as outlined in Appendix A.

Again, the main goal of this flight campaign was to determine if 1090ES is a viable data link for the transmission of turbulence test alert messages. This goal can be satisfied by accomplishing the four objectives defined below:

1) Modification of COTS non-diversity transponder to accommodate turbulence data from a sensor and send it in a 1090 Extended Squitter,
2) Assurance that COTS software provided with the 1090 hardware would recognize the squitter data type associated with the turbulence test alert message,
3) Development of custom code to send emulated turbulence sensor messages,
4) Execution of several flight tests to verify proper operation in a characteristic environment.

4.0 1090ES TEST SYSTEM

The 1090ES Test System involved the use of two aircraft. Each aircraft was equipped with a Commercial Transport 1090ES Flight Rack. Each rack contained a Honeywell KT73 panel mount transponder capable of providing 1090MHz Extended Squitters, a Honeywell KLN94 Global Positioning System (GPS) unit, a WINCOMM Airborne Computer, and a Sensis 1090 Remote Unit (RU). The Sensis RU monitored the incoming turbulence messages and the Honeywell KT73 transmitted the outgoing turbulence messages. Figure 4.0-1 shows the flight rack with their respective connections.

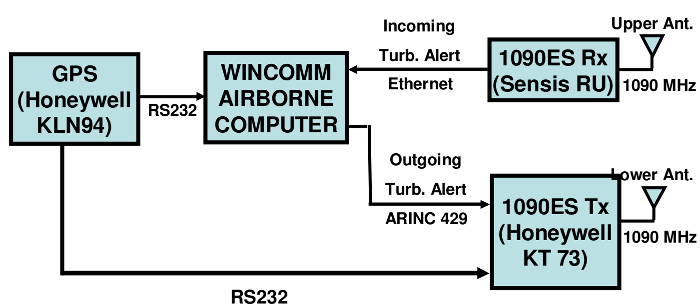


Figure 4.0-1 Commercial Transport 1090ES Flight Rack

The data flow of the 1090ES is also exhibited in figure 4.0-1. Periodically, the Wincomm Airborne Computer would generate a Turbulence Test Alert (TTA) message. This TTA is sent via an ARINC 429 bus to the Honeywell KT73 for transmission. The KT73 encapsulates the TTA as part

of a larger ADS-B message and transmits it. Any 1090ES equipped aircraft would be able to receive the message.

Remember that as a part of this test, there is another nearby aircraft transmitting similar information in the same manner. Again, using figure 4.0-1, this incoming turbulence alert would be received by the Sensis Remote Unit (RU) and forwarded onto the Wincomm Airborne Computer for processing and logging.

The Honeywell KLN94 is used to accurately record the current position of the aircraft. This information is logged for correlation with the 1090ES data as part of the post processing. The KLN94 also feeds GPS data into the KT73 for the standard ADS-B messages.

4.1 HARDWARE

4.1.1 Honeywell KT73

The KT73 is a Commercial Off the Shelf (COTS) transponder that has been slightly modified to accept turbulence (weather) data from a turbulence sensor. The turbulence sensor was emulated on the Wincomm Airborne Computer. The turbulence data that was received from the turbulence sensor is used to generate a 1090 Extended Squitter. It is ultimately transmitted out of the KT73.

4.1.2 Honeywell KLN94

The KLN94 is a Commercial Off the Shelf (COTS) panel mountable color Global Positioning System (GPS) with moving map display.

4.1.3 WINCOMM Airborne Computer

The WINCOMM Airborne Computer (WAC) is an Intel-based rack mount computer running Windows XP. It runs all of the software defined in section 4.2.

4.1.4 Sensis 1090 Remote Unit

The Sensis 1090 Remote Unit (RU) receives the Mode S addressed and Mode S broadcast messages as well as the 1090 Extended Squitters. The RUs also decode, and time stamp ADS-B long squitters, Mode S short squitters, and other Mode S (1090ES turbulence messages) from all targets.

4.2 SOFTWARE

4.2.1 Turbulence Sensor

In lieu of an actual sensors and a turbulence algorithm, custom software was written in LabVIEW to generate turbulence messages. These turbulence messages are also known as Turbulence Test Alert (TTA) messages.

The turbulence test alert messages utilized sixteen (16) bits in the 1090ES message. They were formatted as a payload to a standard ADS-B message, in full compliance with DO-260A. The relatively small size of the TTA can be attributed to the fact that a standard ADS-B message already contains the parameters time, latitude, longitude, and altitude. For the purposes of this test, these 16 bits represented a 16-bit integer that was incremented with each transmission.

A unique ARINC 429 label was assigned to the turbulence data. At a user selectable rate not to exceed every five seconds, a turbulence message was generated and sent to the KT73. Upon successful transmission of the message by the KT73, the TTA message is echoed back to the WAC on a high speed ARINC 429 interface.

The format of the actual turbulence message is outlined in Appendix A, Extended Squitter Format.

4.2.2 GPS Logger

Custom software was developed in LabVIEW to read GPS data from the KLN94. This data was saved and written to disk in one second intervals.

4.2.3 Portable Display Terminal

The Portable Display Terminal (PDT) is software developed by the Sensis Corporation for use in control and monitoring of the 1090 Remote Unit (RU). By applying appropriate filters, the data type of the Turbulence Extended Squitter can be displayed and saved.

4.3 INTERFACES

4.3.1 KLN94 and GPS Logger

The link between the KLN94 and the GPS Logger was an RS-232 port operating at 9600 baud.

4.3.2 KT73 and Turbulence Emulator

The link between the KT73 and the turbulence emulator was ARINC 429. The turbulence data was sent to the KT73 over a low speed ARINC 429 interface. To assure that the turbulence data was received and squittered, an echo was returned on a high speed ARINC 429 link.

4.3.3 PDT and 1090 Remote Unit

The link between the Portable Display Terminal (PDT) and the 1090 Remote Unit was Ethernet running at 10Mbps.

4.3.4 KLN94 and KT73

The link between the KLN94 and the KT73 was an RS-232 port operating at 9600 baud.

5.0 TEST FLIGHTS

5.1 AIRCRAFT

The aircraft used during the test flights were the NASA Glenn Learjet 23 and Learjet 25.

5.2 LOCATION

All of the flights for 1090ES were flown out of Cleveland Hopkins Airport in Cleveland, Ohio.

5.3 TIMES

There were four test flights flown for 1090ES. They were on May 17, May 19 (2), and June 15.

5.4 PATHS

The flight paths are depicted in figures 5.4-1 through 5.4-4. On all of the days except June 15, the most westerly flights are the Learjet 23. On June 15, the Learjet 23 is the easternmost flight.

5.5 TURBULENCE TEST ALERT (TTA) FREQUENCY

The frequency of the TTAs was altered throughout the test flights to provide various loading conditions for the communications link.

On the first test flight, May 17, the TTAs were sent out once every minute. On May 19, the TTAs were transmitted at thirty (30) second and at twenty (20) second intervals for the first and second flights of the day, respectively. On June 15, the interval between transmissions was also set at twenty (20) seconds.

May 17, 2005

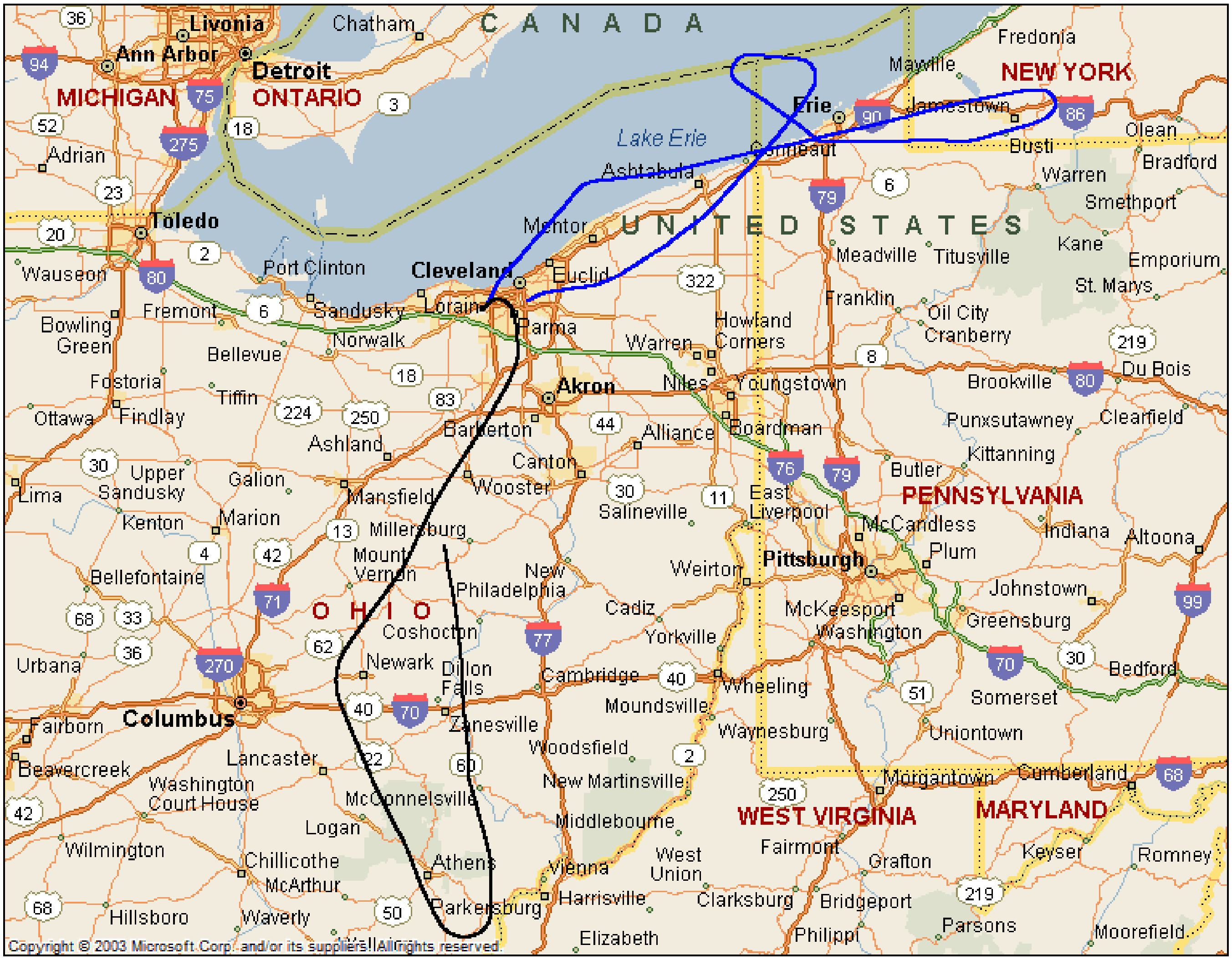


Figure 5.4-1

May 19, 2005 – First Flight

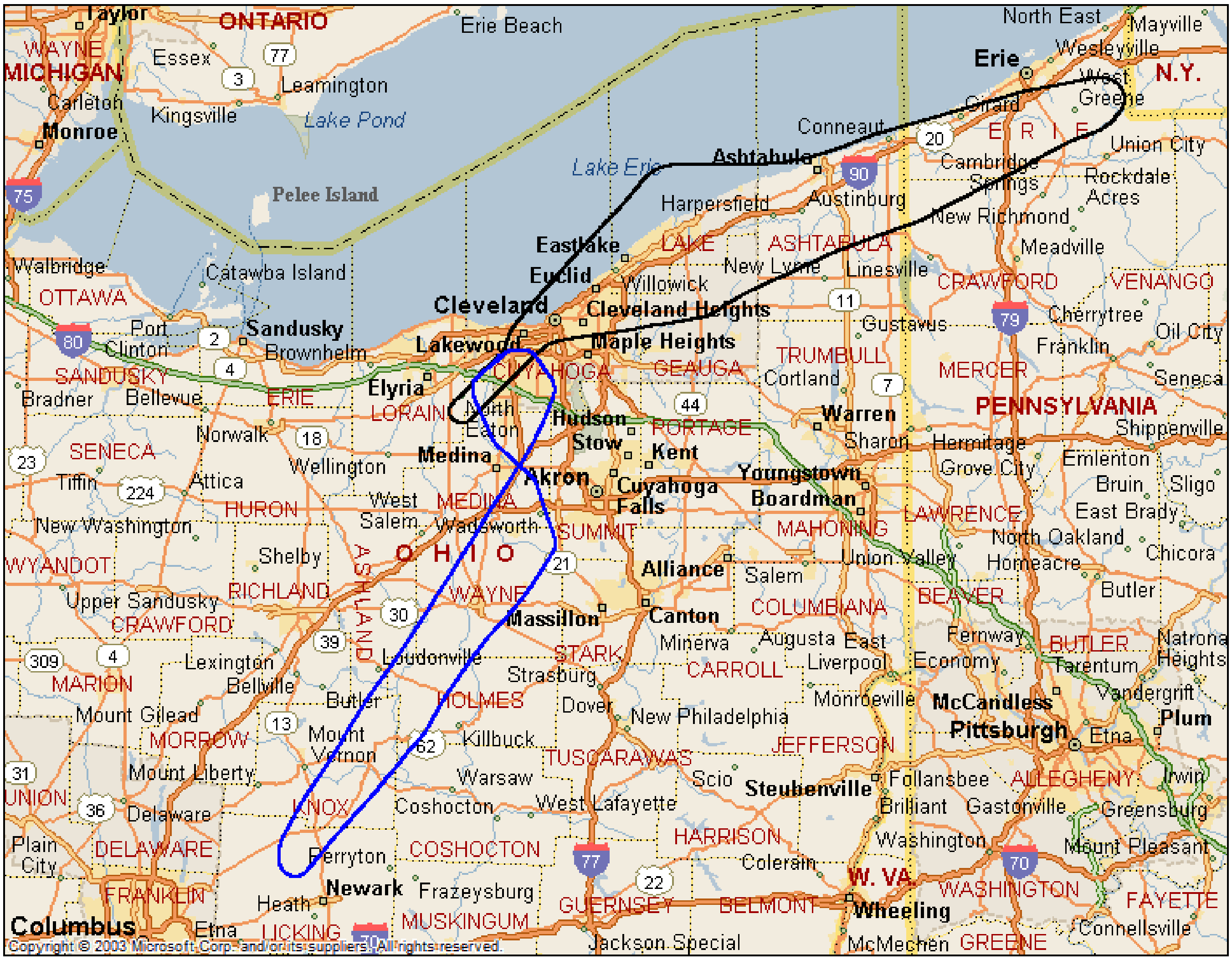


Figure 5.4-2

May 19, 2005 – Second Flight

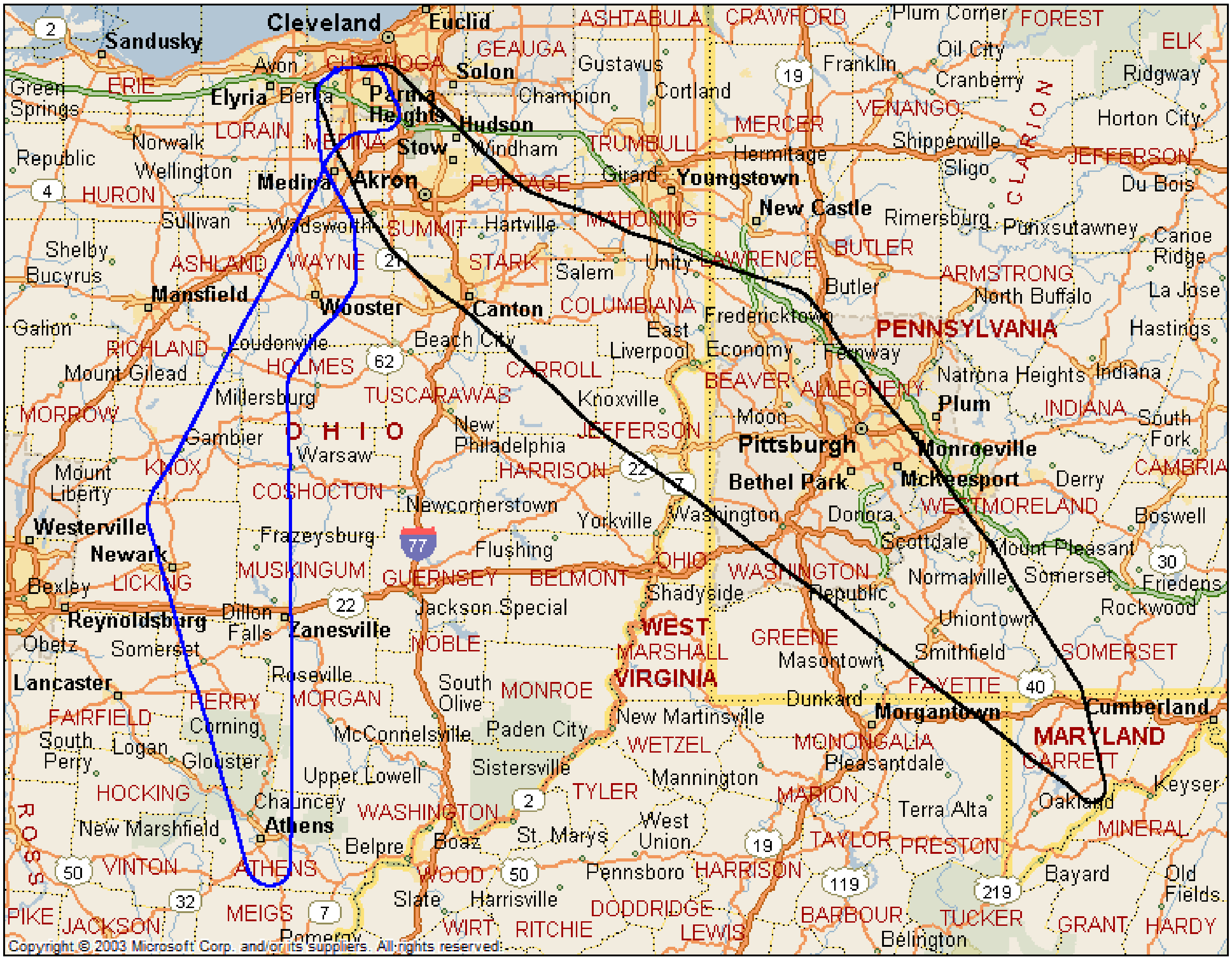


Figure 5.4-3

June 15, 2005

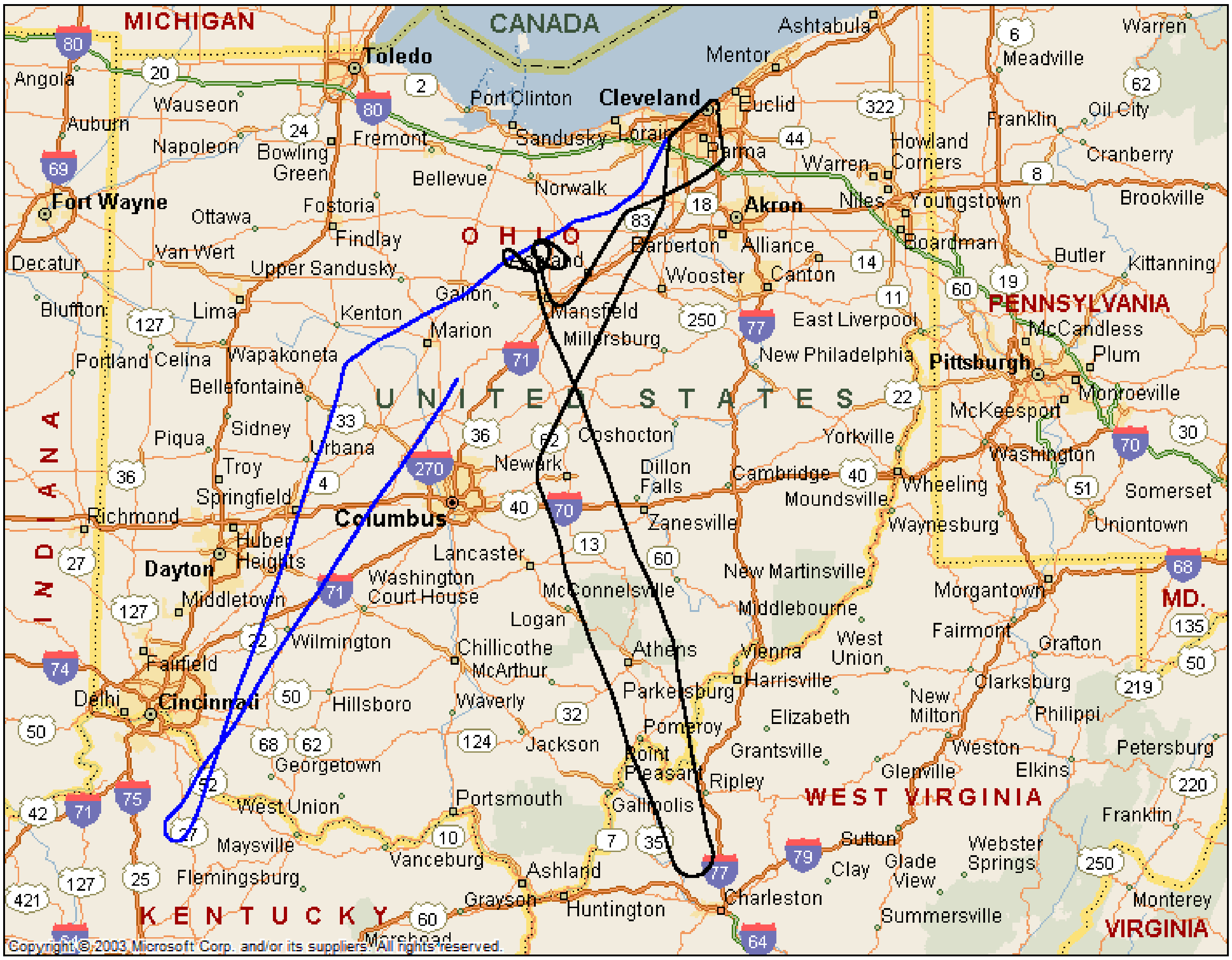
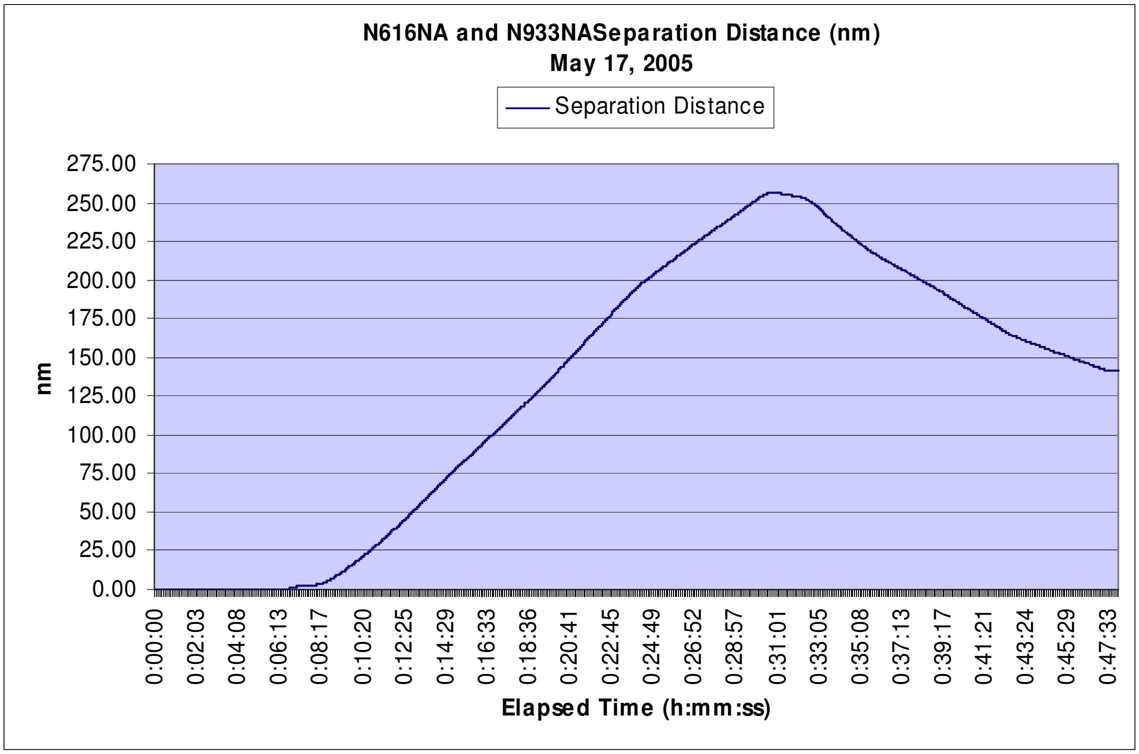


Figure 5.4-4

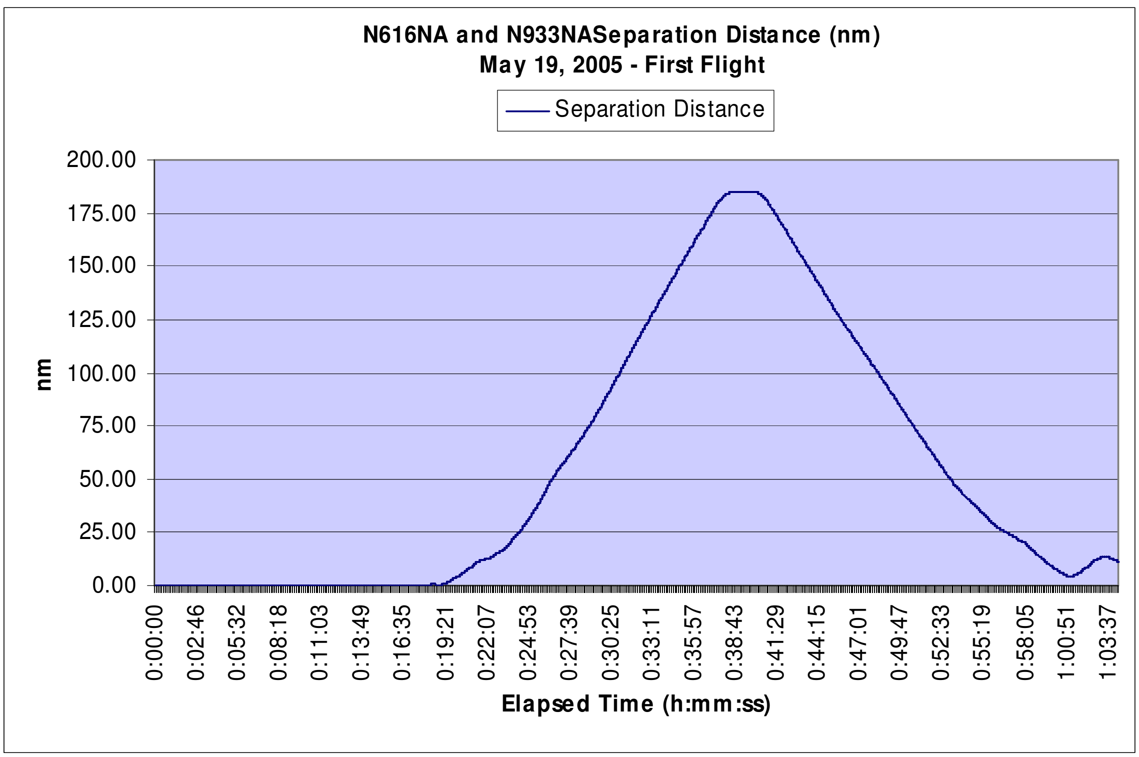
5.6 SEPARATION DISTANCES

The separation distance between the N616NA and N933NA during their flights is depicted in Figures 5.5-1 through 5.5-4. The test requirements estimated a separation distance of 75 nautical miles (nm) based upon power levels, antenna, cable loss, etc. Since the exact range was not known, the separation distance on the first flight was rather large.

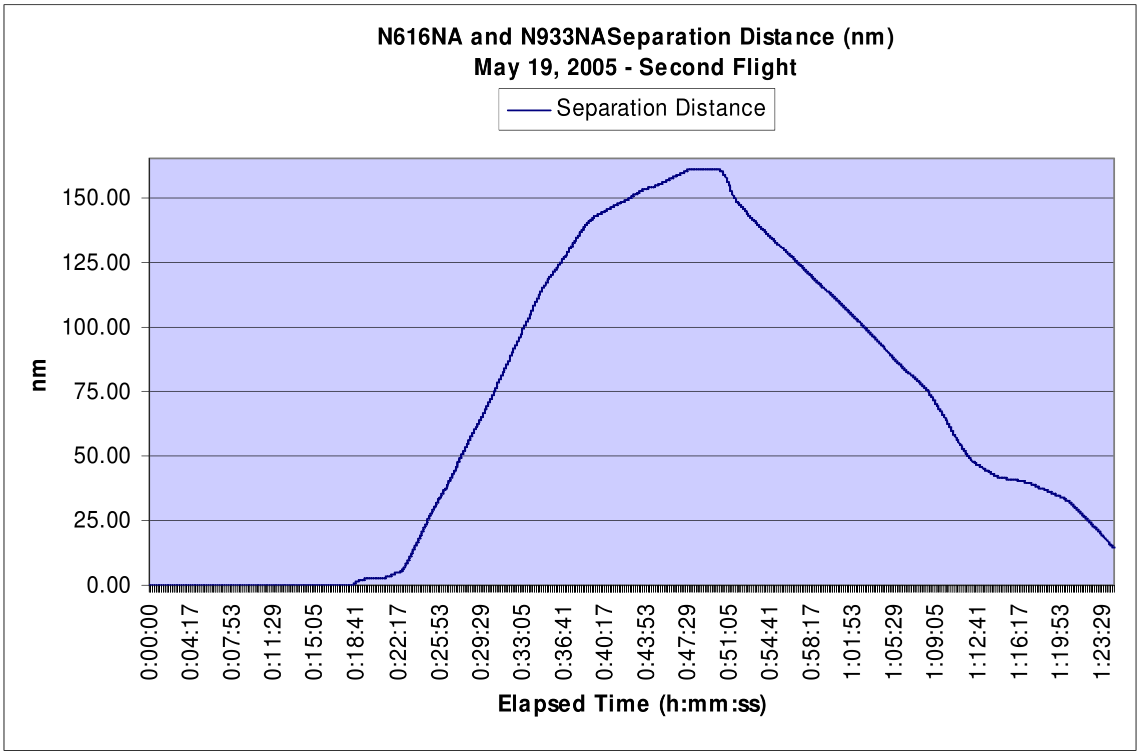
On subsequent flights, a concentrated effort was made to minimize the separation distances. The researchers onboard the aircraft monitored the reception of data from the other aircraft. Once a total loss of data reception was experienced, the flight crew was notified. Working with Air Traffic Control (ATC), the flight crew then attempted to bring the planes closed together to restore the signal.



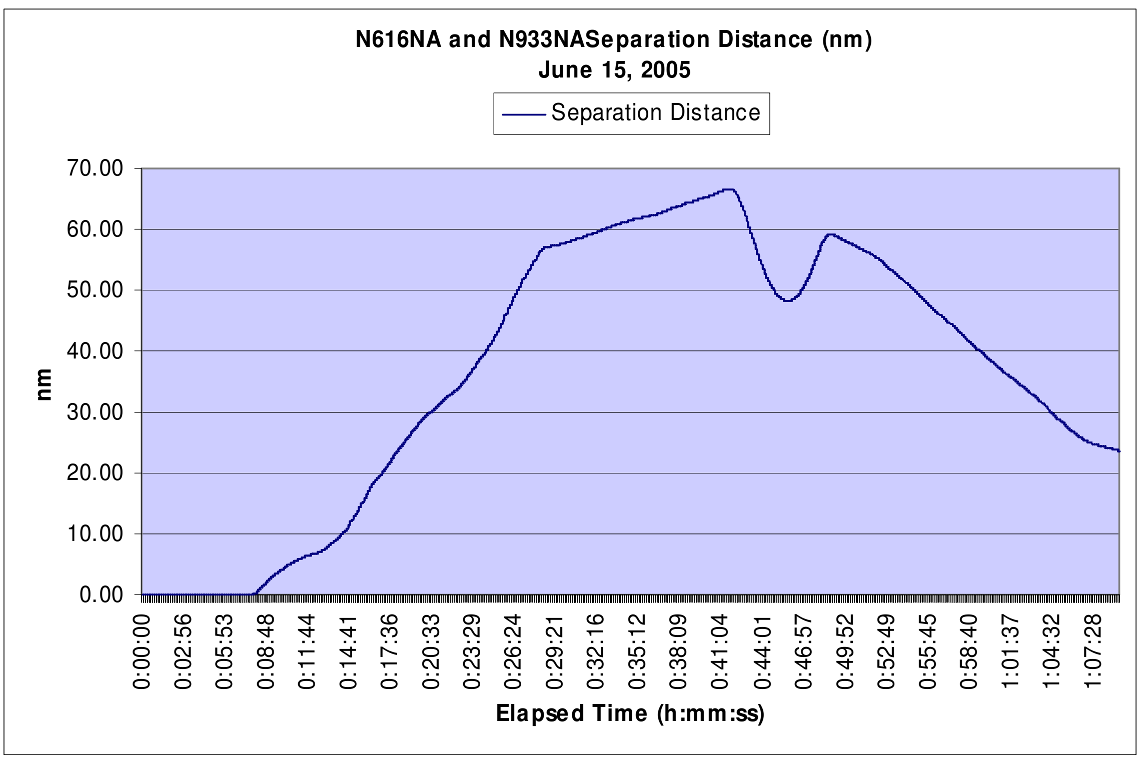
N616NA and N933NASeparation Distance (nm)
May 17, 2005
Separation Distance
nm
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0:00:00
0:02:03
0:04:08
0:06:13
0:08:17
0:10:20
0:12:25
0:14:29
0:16:33
0:18:36
0:20:41
0:22:45
0:24:49
0:26:52
0:28:57
0:31:01
0:33:05
0:35:08
0:37:13
0:39:17
0:41:21
0:43:24
0:45:29
0:47:33
Elapsed Time (h:mm:ss)



N616NA and N933NASeparation Distance (nm)
May 19, 2005 - First Flight
Separation Distance
nm
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0:00:00
0:02:46
0:05:32
0:08:18
0:11:03
0:13:49
0:16:35
0:19:21
0:22:07
0:24:53
0:27:39
0:30:25
0:33:11
0:35:57
0:38:43
0:41:29
0:44:15
0:47:01
0:49:47
0:52:33
0:55:19
0:58:05
1:00:51
1:03:37
Elapsed Time (h:mm:ss)



N616NA and N933NASeparation Distance (nm)
May 19, 2005 - Second Flight
Separation Distance
nm
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0:00:00
0:04:17
0:07:53
0:11:29
0:15:05
0:18:41
0:22:17
0:25:53
0:29:29
0:33:05
0:36:41
0:40:17
0:43:53
0:47:29
0:51:05
0:54:41
0:58:17
1:01:53
1:05:29
1:09:05
1:12:41
1:16:17
1:19:53
1:23:29
Elapsed Time (h:mm:ss)



N616NA and N933NASeparation Distance (nm)
June 15, 2005
Separation Distance
nm
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0:00:00
0:02:56
0:05:53
0:08:48
0:11:44
0:14:41
0:17:36
0:20:33
0:23:29
0:26:24
0:29:21
0:32:16
0:35:12
0:38:09
0:41:04
0:44:01
0:46:57
0:49:52
0:52:49
0:55:45
0:58:40
1:01:37
1:04:32
1:07:28
Elapsed Time (h:mm:ss)

6.0 TEST RESULTS

6.1 Raw 1090ES Data

Table 6.1-1 outlines the number of 1090 Extended Squitters sent and received on the various flight dates. The direction is the path of the data (i.e. 616 to 933, would be data sent from the Learjet 25 N616NA and received on the Learjet N933NA). It should be noted that this table includes all 1090ES messages sent, including those sent while the two airplanes set side by side on the tarmac. In section 7.0 and the respective tables, messages sent and received when the two aircraft were less than three (3) nautical miles were filtered out.

Date	Direction	Sent	Received	% Received
May 17	616 to 933	42	20	47.6%
May 17	933 to 616	28	17	60.7%
May 19 – 1	616 to 933	98	26	26.5%
May 19 – 1	933 to 616	130	40	30.8%
May 19 – 2	616 to 933	240	70	29.2%
May 19 – 2	933 to 616	253	76	30.0%
June 15	616 to 933	87	27	31.0%
June 15	933 to 616	230	47	20.4%
TOTAL		1108	323	29.2% (average)

Table 6.1-1 1090 Extended Squitters Sent and Received

6.2 Distribution of 1090ES Messages received versus Confidence Level

1090 Extended Squitters that are received at the Remote Unit (RU) are decoded and monitored by the Portable Display Terminal (PDT). The PDT software will display the Confidence Level of each squitter. Possible values and the respective meaning of the Confidence Level are depicted in table 6.2-1.

CONFIDENCE LEVEL	MEANING
0	Too many errors to correct
1	Reply error detected and not corrected
2	Reply error detected and corrected
3	Reply decoded with no corruption detected

Table 6.2-1 Confidence Levels

All four of the confidence levels were seen during the 1090ES flight tests. Table 6.2-2 represents the distribution of the Confidence Levels (CL) for each of the flights.

Date	Direction	Received	CL3	CL2	CL1	CL0
May 17	616 to 933	20	20	0	0	0
May 17	933 to 616	17	17	0	0	0
May 19 – 1	616 to 933	26	22	3	0	1
May 19 – 1	933 to 616	40	36	1	3	0
May 19 – 2	616 to 933	70	64	4	2	0
May 19 – 2	933 to 616	76	67	5	1	3
June 15	616 to 933	27	26	0	1	0
June 15	933 to 616	47	36	4	7	0
TOTAL		323	288	17	14	4
% of TOTAL			89.2	5.3	4.3	1.2

Table 6.2-2 Confidence Level Distribution

6.3 Distribution of 1090ES Messages received versus Separation Distance between the Aircraft

The test flights were conducted under level flight conditions with each aircraft at relatively the same altitude. The initial requirements were to keep the separation distance around 75 nautical miles. However, a decision made at flight time was to fly until coverage was lost. On subsequent flights, every attempt was made to minimize the separation distance. It should be noted that the Cleveland Hopkins airport is not far from the Cleveland Air Route Traffic Control Center (ARTCC), one of the busiest such facilities in the world. Therefore, the most desirable routes were not always readily available, especially on a short notice.

As expected, the number of 1090ES received dropped off as a function of distance. However, on May 17, a notable number of

valid Turbulence Test Alert messages were received at distances greater than 150nm. These distances greatly exceed the 90nm for low density environments stated in the ADS-B MASPS.

It is beyond the scope of this document to formulate a justification for this. In addition, no roll, pitch, or yaw data was accumulated during these flights. However, it is surmised that the orientation of the antennas had an affect on the performance of the link on this particular day.

On June 15, it is apparent that N616NA suffered a software or hardware failure. As can be seen from Figure 6.3-1, the only data that is available is while the two aircraft are still parked at the hangar (the separation distance never increases). Reviewing the GPS data that was logged for both the N616NA and N933NA reinforces this premise. The GPS data gathered on the N616NA ended over forty (40) minutes before the data logging stopped on the N933NA.

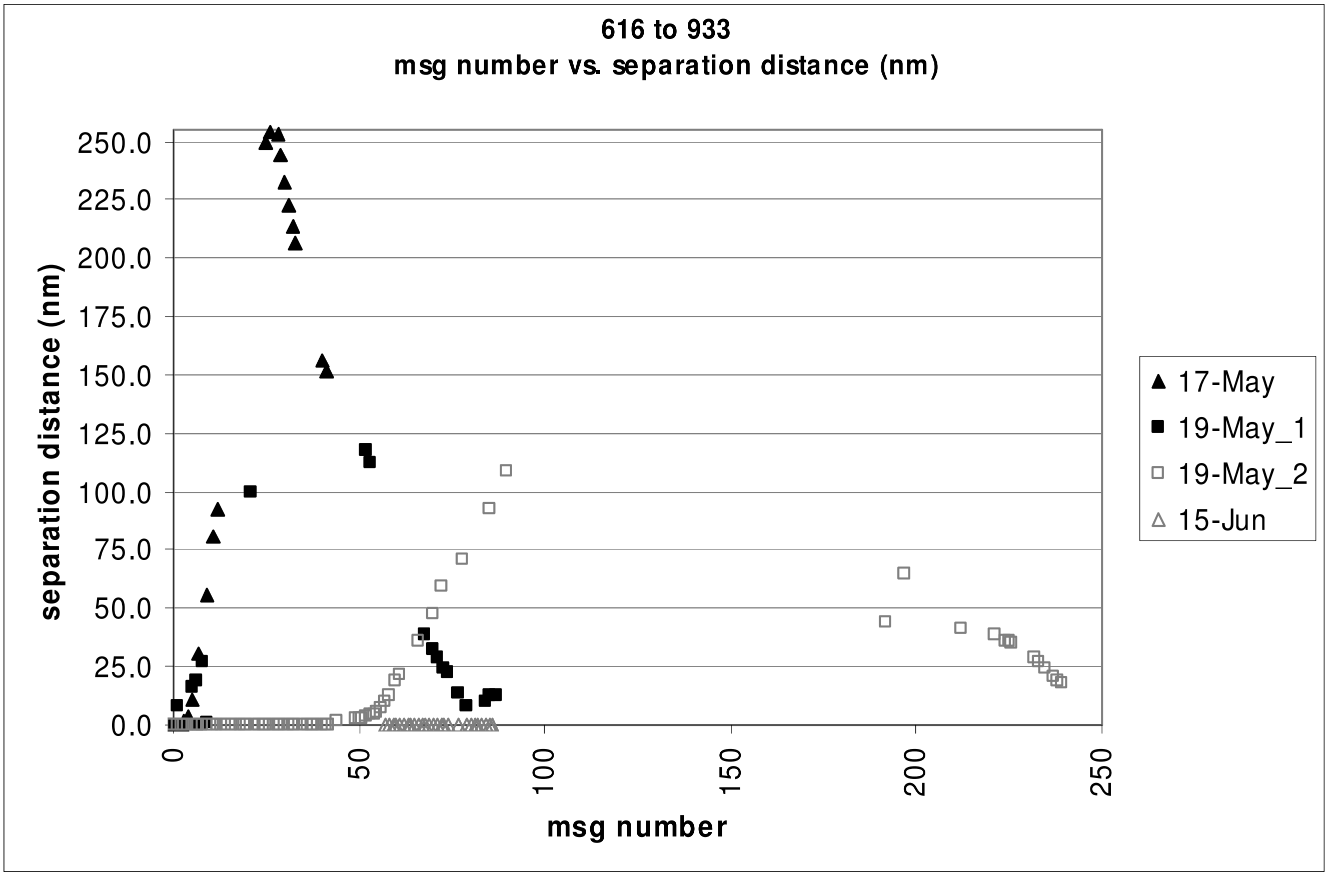


FIGURE 6.3-1 Turbulence Message Number versus Separation Distance

616 to 933

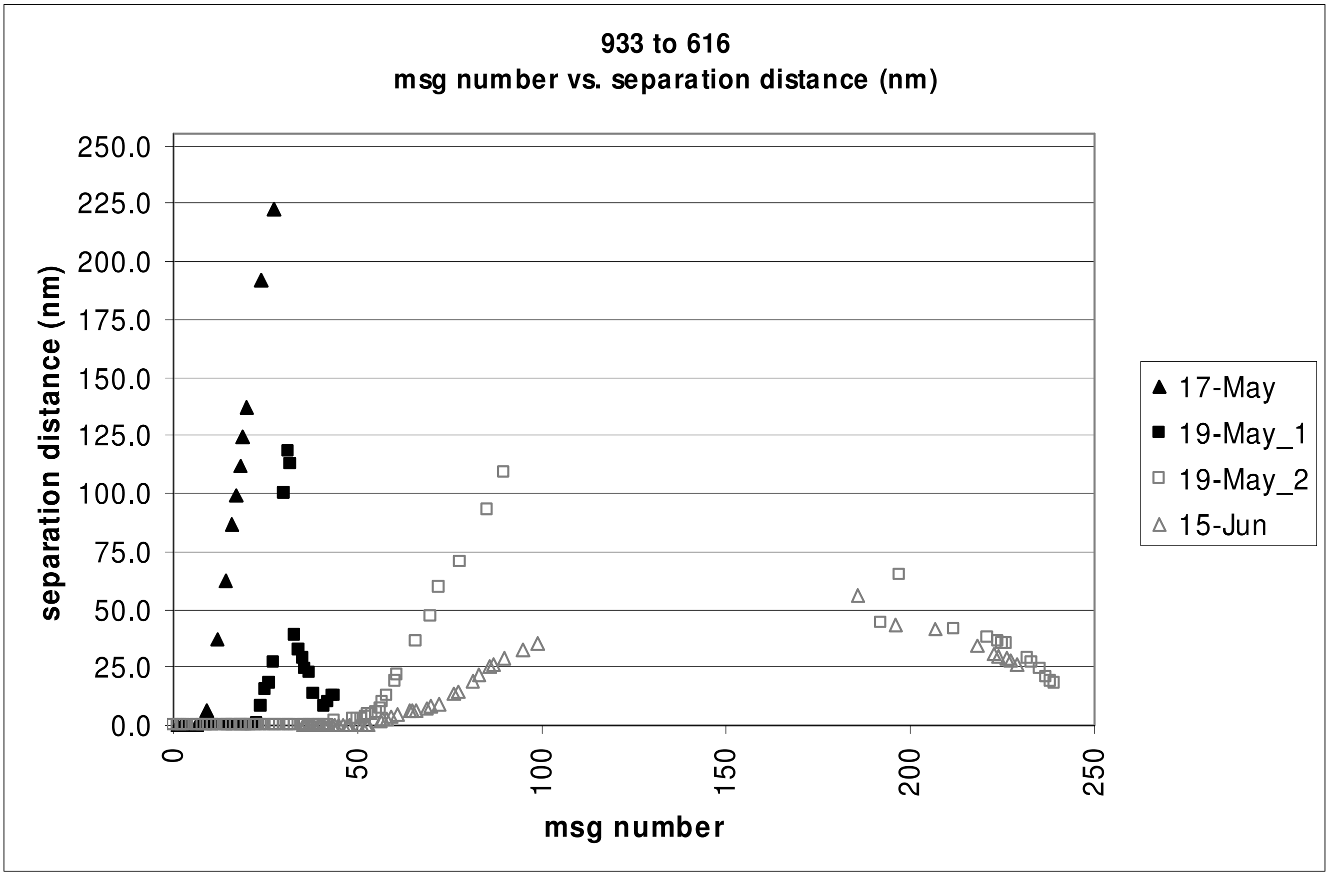


FIGURE 6.3-2 Turbulence Message Number versus Separation Distance

933 to 616

7.0 CONCLUDING REMARKS

As outlined in section 3.0, there were four (4) objectives established for the Commercial Transport Scenario 1090 Extended Squitter Tests. The first objective was to show that a COTS transponder with only a minor modification can receive data from a turbulence sensor and send this data over a 1090 link. This objective was met by a contract to Honeywell to modify a KT73.

The second objective was to ensure existing 1090 monitoring software provided with the 1090 equipment would recognize the message type of the Turbulence Extended Squitter. This was accomplished via laboratory testing with the Portable Data Terminal and the respective software. This was completed.

As stated earlier, a deployed system would utilize a turbulence algorithm that receives input from various sensors onboard the aircraft to generate a turbulence alert message. However, it was beyond the scope of this effort to develop such an algorithm. In addition, when it was realized that the aircraft would have to fly through turbulence to generate a message and the number of messages actually generated may be small, a turbulence sensor emulator idea surfaced. This was accomplished by developing custom code and thus satisfied the third objective.

The final objective was to demonstrate the technology in a characteristic environment. This was accomplished by the four flights campaigns. The performance characteristics of the Learjet’s are very similar to those of a commercial transport aircraft, in speed and altitude ability. In addition, the air traffic density of the Cleveland Sector presents essentially a worst case scenario. The Cleveland Sector was the densest at the time of this writing. Thus, the flights were very representative of an environment in which 1090 would expect to experience.

Overall, the tests exhibited that 1090 is a capable means of broadcasting aviation turbulence data between aircraft. As can be seen from the tables 7.0-1 and 7.0-2, when the received data is filtered to a separation distance between 3 and 100 nautical miles (100nm has been identified as the range of a terminal area squitter station [RTCA2003]), the number of messages received is nearly 25%. Three nautical miles was chosen as the lower limit as this is the minimum distance specified for the separation of aircraft operating within 40 miles of a radar antenna site [FAA2004]. The lower limit of three nautical miles has the benefit of eliminating the messages sent and received while the two planes were sitting side by side on the tarmac. As would be expected, these messages had a very high success rate.

Date	Direction	Largest Separation Distance Recorded (nm)	Separation Distance (nm)	Sent	Received	% of sent messages received
May 17	616 to 933	256.4	3≤sd≤100	9	6	66.7
			>100	29	10	34.5
May 17	933 to 616		3≤sd≤100	11	5	45.5
			>100	10	5	50.0
May 19 – 1	616 to 933	184.8	3≤sd≤100	54	15	27.8
			>100	34	2	5.9
May 19 -1	933 to 616		3≤sd≤100	53	16	30.2
			>100	34	0	0.0
May 19 - 2	616 to 933	160.8	3≤sd≤100	98	27	27.6
			>100	90	1	1.1
May 19 – 2	933 to 616		3≤sd≤100	105	28	26.7
			>100	88	0	0.0
June 15	616 to 933	66.6	3≤sd≤100	0	0	0.0
			>100	n/a	n/a	n/a
June 15	933 to 616		3≤sd≤100	171	26	15.2
			>100	n/a	n/a	n/a

Table 7.0-1 1090ES Sent and Received as a function of Separation Distance (nm)

	Direction	Largest Separation Distance Recorded (nm)	Separation Distance (nm)	Sent	Received	% of total received
TOTALS	616 to 933	256.4	3≤sd≤100	161	48	29.8
			>100	153	13	8.5
	933 to 616		3≤sd≤100	340	75	22.1
			>100	132	5	3.8
	COMBINED		3≤sd≤100	501	123	24.6
			>100	285	18	6.3

Table 7.0-2 1090ES Sent and Received as a function of Separation Distance (nm) (compilation)

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9.0 ACRONYMS

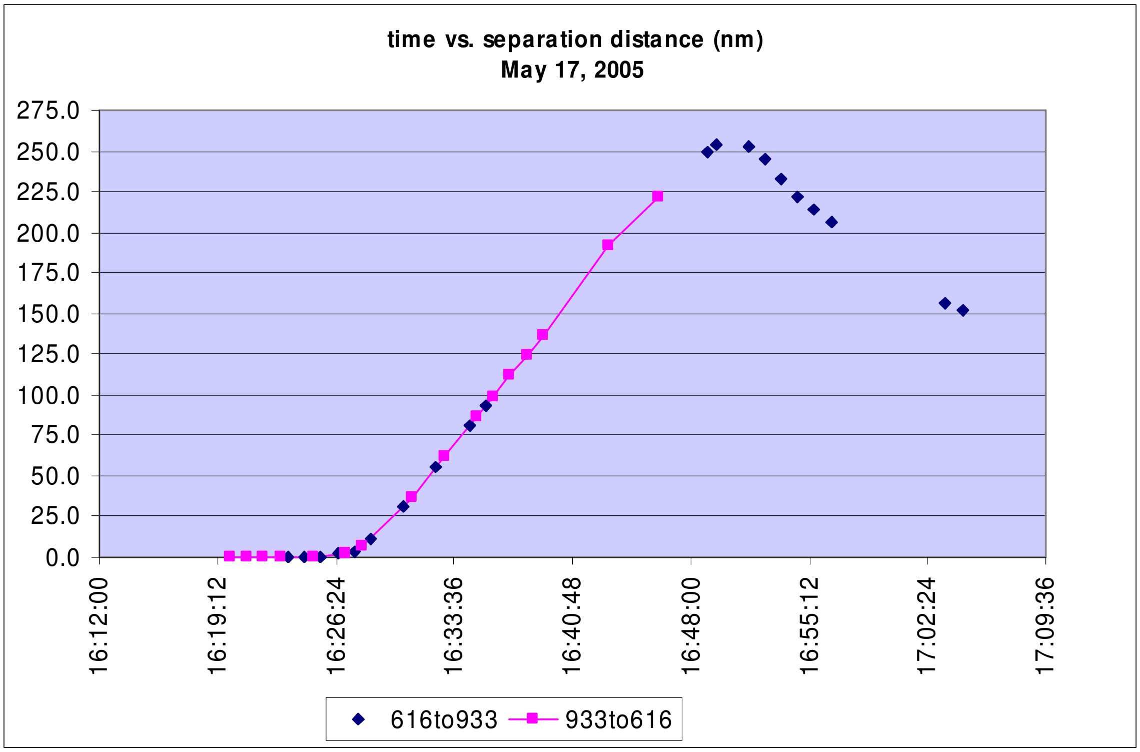
ADS-B	Automatic Dependent Surveillance – Broadcast
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
CL	Confidence Level (as it refers to a 1090ES)
COTS	Commercial Off the Shelf
ES	Extended Squitter
FAA	Federal Aviation Administration
GPS	Global Positioning System
PDT	Portable Display Terminal
RU	Remote Unit
TTA	Turbulence Test Alert message
VDLM3	VHF Data Link Mode 3
WAC	Wincomm Airborne Computer
WINCOMM	Weather Information Communications
1090ES	1090MHz Extended Squitter

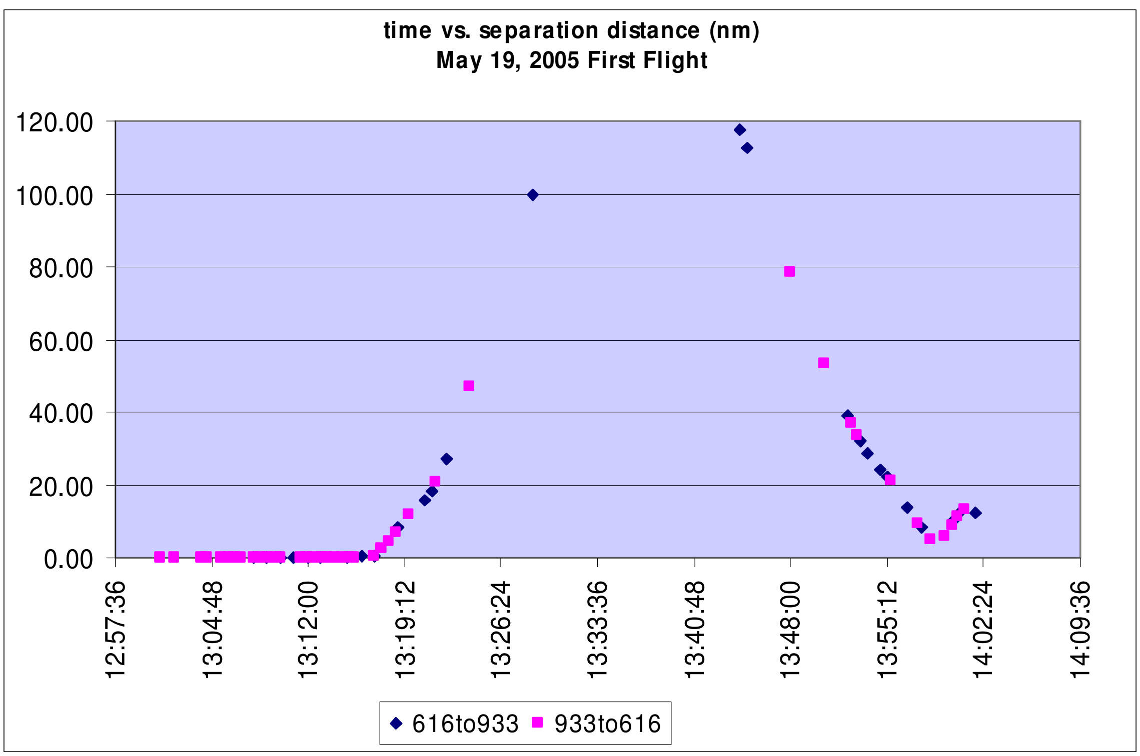
APPENDIX A

EXTENDED SQUITTER FORMAT

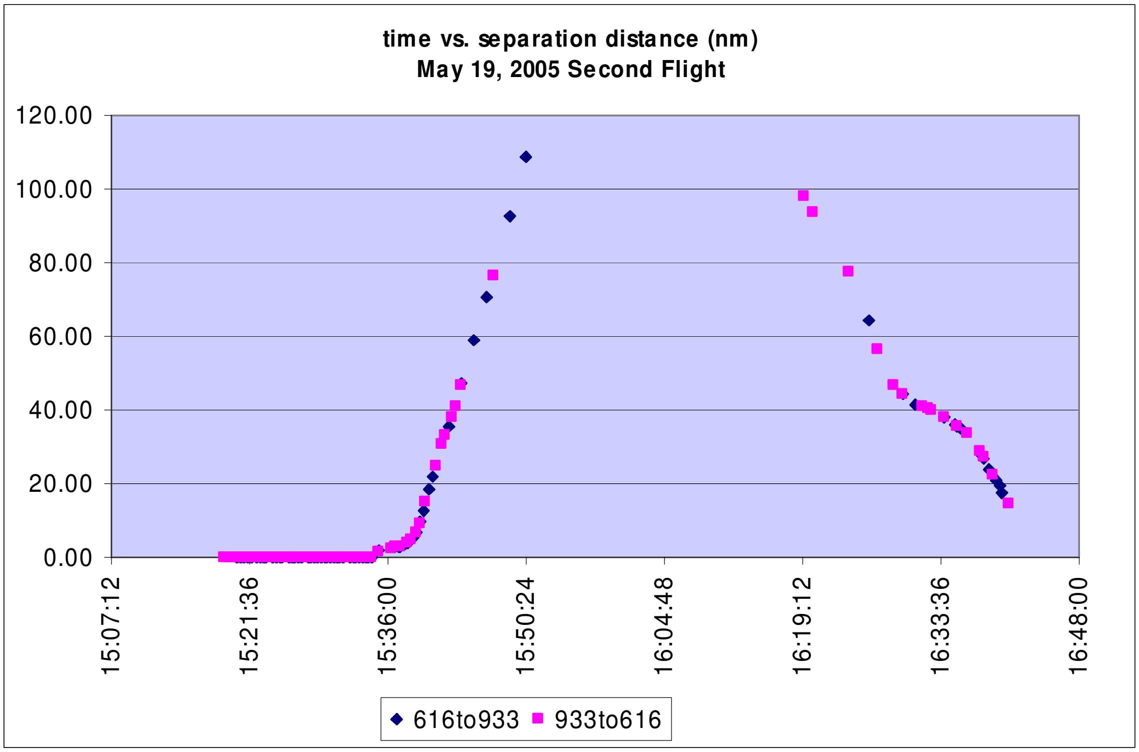
1	**MSB**	**1**
2		**0**
3	**DATA TYPE CODE = 23 (TEST)**	**1**
4		**1**
5	**LSB**	**1**
6		**1**
7	**SUBTYPE CODE = 6**	**1**
8		**0**
9	**MSB**	**0 or 1**
10		**0 or 1**
11		**0 or 1**
12	**Turbulence Message Byte 1**	**0 or 1**
13		**0 or 1**
14		**0 or 1**
15		**0 or 1**
16	**LSB**	**0 or 1**
17	**MSB**	**0 or 1**
18		**0 or 1**
19		**0 or 1**
20	**Turbulence Message Byte 2**	**0 or 1**
21		**0 or 1**
22		**0 or 1**
23		**0 or 1**
24		**0 or 1**
25 - 56	**Padded with Zeros**	**0**

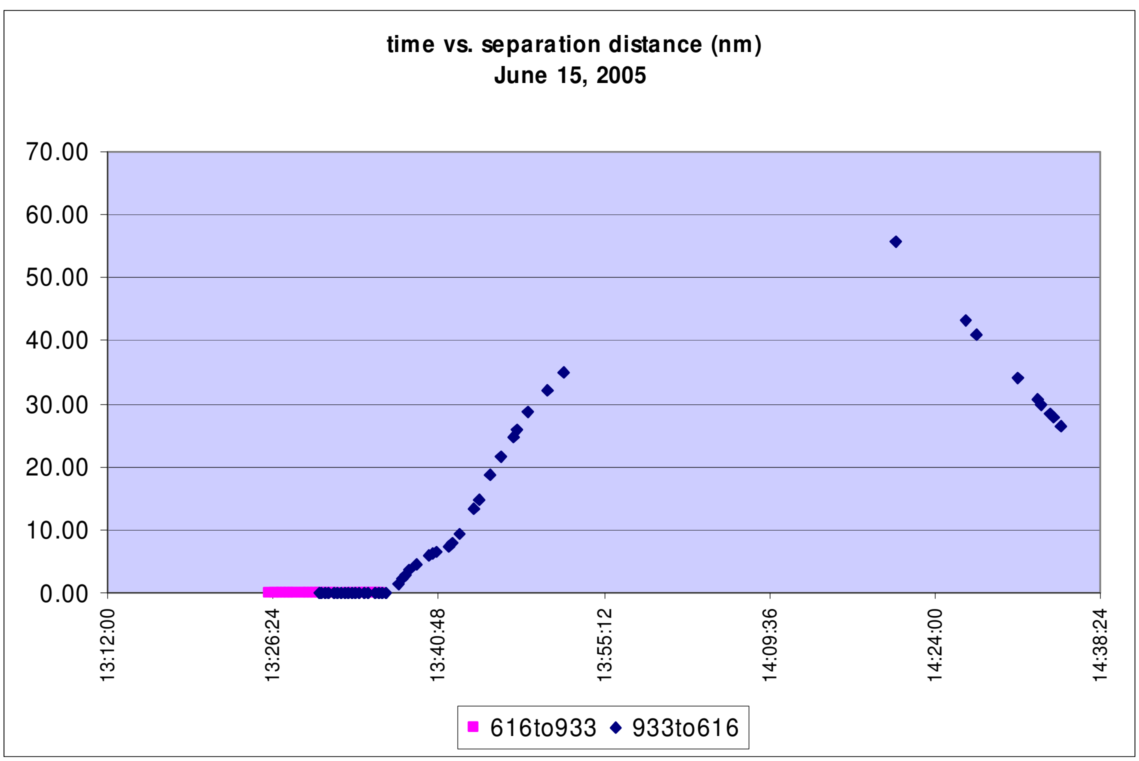
APPENDIX B: Ancillary Data





APPENDIX B (cont.): Ancillary Data





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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
June 2006

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Weather Information Communication (WINCOMM) VDL–3 and 1090ES Final Test Requirements, Test Plans, and Test Results

5. FUNDING NUMBERS
WBS 645846.02.07.03

6. AUTHOR(S)
James H. Griner, Russ Jirberg, Brian Frantz, and Brian A. Kachmar

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E–15628

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM—2006-214353

11. SUPPLEMENTARY NOTES
James H. Griner, Glenn Research Center; Russ Jirberg, Lake Logic Systems, Cleveland, Ohio, 44134; Brian Frantz, Verizon Federal Network Systems, 21000 Brookpark Road, Cleveland, Ohio 44135; and Brian A. Kachmar, Analex Corporation, 1100 Apollo Drive, Brook Park, Ohio 44142. Responsible person, James H. Griner, organization code RCN, 216–433–5787.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Categories: 04 and 06

Available electronically at http://gltrs.grc.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***
NASA's Aviation Safety Program was created for the purpose of making a significant reduction in the incidents of weather related aviation accidents by improving situational awareness. The objectives of that program are being met in part through advances in weather sensor technology, and in part through advances in the communications technology that are developed for use in the National Airspace System. It is this latter element, i.e., the improvements in aviation communication technologies, that is the focus of the Weather Information Communications project. This report describes the final flight test results completed under the WINCOMM project at the NASA Glenn Research Center of the 1090 Extended Squitter (1090ES) and VDL Mode 3 (VDL–3) data links as a medium for weather data exchange. It presents the use of 1090ES to meet the program objectives of sending broadcast turbulence information and the use of VDL–3 to send graphical weather images. This report provides the test requirements and test plans, which led to flight tests, as well as final results from flight testing. The reports define the changes made to both avionics and ground-based receivers as well as the ground infrastructure to support implementation of the recommended architecture, with a focus on the issues associated with these changes.

14. SUBJECT TERMS
Flight tests; Data links; Telecommunication; Turbulence; Flight safety; Aircraft safety; Aircraft accidents

15. NUMBER OF PAGES
113

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	